INTERIM GEOLOGIC MAP OF THE CENTER CREEK QUADRANGLE, WASATCH COUNTY, UTAH

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ABSTRACT

The Center Creek quadrangle lies astride a structural and topographic saddle between the Wasatch Range and Uinta Mountains. The quadrangle includes three distinct sequences of rocks: (1) allochthonous, Pennsylvanian to Permian Oquirrh Formation strata in the upper plate of the Charleston thrust that are deformed into two principal, southeast-plunging folds; (2) autochthonous, southwest-dipping Mesozoic strata in the lower plate of the Charleston thrust; and (3) subhorizontal Eocene to Oligocene clastic and volcanic rocks that unconformably overlie both upper and lower plate strata.

Allochthonous strata are bounded on the northeast by the Charleston thrust, which trends southeast up the Center Creek drainage under a cover of Quaternary deposits. The thrust ramps stratigraphically upsection to the northeast, and at the surface places the Late Pennsylvanian Wallsburg Ridge Member of the Oquirrh Formation against strata herein assigned to the undifferentiated lower Frontier Formation and underlying unnamed shale unit of early Late Cretaceous (middle to late Cenomanian) age. The distribution of the early Tertiary Keetley Volcanics – which here consist of a lower tuffaceous unit, a middle quartzite-boulder unit that thins to the northeast, and the upper volcanic breccia of Coyote Canyon – demonstrates post-Keetley extensional faulting from the mouth of the Center Creek drainage south-southeast to the southern boundary of the quadrangle. The down-to-the-west displacement on this normal fault or series of faults is about 1,000 feet (305 m).

Deposits and landforms associated with the Pinedale and possibly Bull Lake glaciations are present in the Lake Creek drainage, and Pinedale glacial deposits are newly recognized in the

Center Creek drainage. Hummocky ground moraine, lateral and end moraines, and broad cirques in the adjacent Heber Mountain quadrangle characterize these drainages. Glacial outwash deposits are widespread in the eastern portion of Heber Valley, and may be present in the lower reaches of both the Center Creek and Lake Creek drainages.

The principal economic resources of the quadrangle are aggregate, particularly crushed quartzite from the Wallsburg Ridge Member of the Oquirrh Formation, and rough building stone quarried from the Nugget Sandstone. Numerous springs and streams in the quadrangle, and ground water from the eastern end of Heber Valley, provide water for domestic use and irrigation.

Geologic hazards in the Center Creek quadrangle include landslides, flooding, debris flows, shallow ground water, problem soil and rock, earthquakes, and radon. We mapped numerous landslides in the quadrangle, many of which show evidence of historical movement. Some of these landslides were previously unmapped, including ridge-top deformation features that may be sackungen and which are thought to result from large-scale, deep-seated gravitational spreading. Landslides typically occur in Pleistocene glacial deposits, the Keetley Volcanics, and Cretaceous strata, as well as colluvial and residual deposits derived from these units.

INTRODUCTION

The Center Creek quadrangle lies about 35 miles (56 km) southeast of Salt Lake City in a structural and topographic saddle between the Wasatch Range and Uinta Mountains. The quadrangle includes the eastern part of Heber Valley and adjacent foothills, which are experiencing significant population growth (figure 1). Geologic hazards associated with landslides, earthquakes, flooding, problem soils, and other factors are known in the quadrangle and surrounding area. This geologic map and report provide basic geologic information necessary to further evaluate the geologic hazards and resources in the area.

Figure 1 near here

The Center Creek quadrangle lies in what Stokes (1986) referred to as the Wasatch Hinterlands portion of the Middle Rocky Mountains physiographic province. The quadrangle includes the lower parts of three principal drainages: Daniels Canyon, which is traversed by U.S. Highway 40; Center Creek, which occupies a structural divide between upper and lower plate strata; and Lake Creek, which is the site of significant residential development. Elevations in the quadrangle range from about 5,800 feet (1,770 m) in the northwest to 9,200 feet (2,800 m) in the southeast parts of the quadrangle. Much of the southern half of the quadrangle is public land managed by the U.S. Forest Service, whereas most land in the northern half of the quadrangle is privately owned.

The Uinta Mountains and Wasatch Range have been the focus of numerous stratigraphic, structural, and economic investigations. In contrast, the geology of the Center Creek quadrangle has not been widely studied, principally due to generally poor and limited bedrock exposures. Baker (1959) produced a 1:215,000-scale geologic map of the greater Wasatch Range near Provo, including the Center Creek quadrangle. He first mapped the Center Creek quadrangle in some detail, however, at a scale of 1:63,360 as part of his larger map of the west half of the Strawberry Valley quadrangle (Baker, 1976). In his unpublished 1980 to 1981 study of the stratigraphy and structure of Pennsylvanian-Permian strata of part of the Charleston allochthon, co-author John Welsh mapped most of the Center Creek and adjacent Charleston, Co-op Creek, and Twin Peaks quadrangles at a scale of 1:24,000. In his 1:500,000-scale geologic map of Utah, Hintze (1980) mapped an erosional window through upper-plate rocks of the Charleston thrust at Center Creek that showed a structurally complex sequence of Late Paleozoic to Eocene strata, but that we interpret differently. Bryant (1992) completed a 1:125,000-scale geologic map of the Salt Lake City 1^0 x 2^0 quadrangle and was the first to identify Cretaceous strata in the Center Creek quadrangle. Geologic maps of adjacent areas include those of Bissell (1952), who mapped the northeast Strawberry Valley quadrangle at a scale of 1:87,000; Bromfield and others (1970), who mapped the Heber quadrangle at 1:24,000; McDougald (1953), who mapped the Francis area at a scale of 1:31,680; and Astin (1976), who provided a 1:48,000-scale map of the Co-op Creek quadrangle. Bryant (1990) produced a map of the Salt Lake City 30 x 60-minute quadrangle. Hylland and others (1995) produced an engineering geologic map folio of western Wasatch County, which includes most of the Center Creek quadrangle.

STRATIGRAPHY

The Center Creek quadrangle includes three distinct sequences of rocks: allochthonous, Pennsylvanian to Permian rocks in the upper plate of the Charleston thrust that are deformed into two principal, southeast-plunging folds; autochthonous, southwest-dipping Mesozoic strata in the lower plate of the Charleston thrust; and Eocene to Oligocene clastic and volcanic rocks that unconformably overlie both upper and lower plate strata and mostly conceal the Charleston thrust. A variety of Quaternary deposits, including high-level alluvial deposits in Daniels Canyon and glacial deposits in both the Lake and Center Creek drainages, record the evolution of the present landscape.

Unlike areas to the south and east near the Strawberry and Nebo thrusts, there are no coarse, middle to late Cretaceous synorogenic strata preserved in front of the Charleston thrust. Such sediments certainly were deposited in front of the Charleston thrust as they were to the south along the Strawberry-Nebo thrust, but were likely eroded as a result of subsequent uplift of the Uinta Mountains. Some synorogenic deposits could be preserved beneath a cover of Keetley Volcanics in the structural saddle between the Uinta Mountains and Wasatch Range.

Pennsylvanian and Permian

Oquirrh Formation

Oquirrh strata consist of up to 25,000 feet (7,600 m) of Pennsylvanian to Lower Permian sandstone, orthoquartzite, shale, and limestone deposited in the Oquirrh basin of north-central Utah and southern Idaho (Welsh and Bissell, 1979). These beds attain group status in the Oquirrh Mountains and Tintic district to the west, but in the Wasatch Range were conferred the rank of formation by Baker (1976). In the Wasatch Range, the Oquirrh Formation is divided into five members: in ascending order these are the Bridal Veil Falls, Bear Canyon, Shingle Mill Limestone, Wallsburg Ridge, and Granger Mountain Members. Only the upper part of the Bear Canyon Member through the basal Granger Mountain Member is exposed in the Center Creek quadrangle. Regional correlation of member and formational names are summarized by Baker (1976) and Welsh and Bissell (1979).

Bear Canyon Member (IPobc): Only about the upper 2,000 feet (610 m) of the Bear Canyon Member is exposed in the Center Creek quadrangle where it forms steep, ledgy slopes mostly covered by scree in the core of the Daniels Canyon anticline. The upper Bear Canyon Member consists mostly of sandstone with lesser interbedded limestone. The sandstone is yellowish brown, very fine grained, finely laminated, feldspathic, and is well indurated with a siliceous or less commonly calcareous cement. Most sandstone beds are resistant and commonly display a prominent conchoidal fracture like quartzite or orthoquartzite. The sandstones commonly have a light-yellow goethetic stain from a trace of pyrite.

The limestones of the upper Bear Canyon Member are exposed immediately north of State Highway 40 in the NE1/4 section 27 and in the SW1/4SE1/4 section 36, T. 4 S., R. 5 E. These limestones are principally medium to thick bedded, medium gray, coarse grained, and fossiliferous, with local black chert nodules and stringers. Limestones exposed near State

Highway 40 lie on the south flank of the Daniels Canyon anticline and total several tens of feet thick. The limestones become thicker bedded and sandy with planar cross-laminae and less chert down section to the north. The cross-laminae weather brown and gray, with the brown, coarser grained laminae standing in relief. Crinoid stems, fenestrae bryozoans, and small brachiopod fossils are common in these beds. These limestone beds are not exposed on the north flank of the anticline due to truncation by a northwest-trending, down-to-the-north normal fault. Based on map patterns and assuming minimal structural complications that may be concealed by surficial deposits of Daniels Canyon, these limestone beds probably lie about 1,500 to 1,800 feet (460-550 m) below the top of the Bear Canyon Member.

Two limestone beds, each about 10 feet (3 m) thick, are in section 36, on the nose of the Daniels Canyon anticline. These limestone beds are separated by a covered interval about 20 feet (6 m) thick that probably consists of light-olive-gray, very fine- to fine-grained calcareous sandstone similar to that which is exposed below the lower limestone. The enclosing carbonate units are thin- to very thick-bedded, generally fine- to medium-grained limestone with about 10 percent black chert stringers. These limestones contain rugose corals and partially articulated crinoid stems. Limestones of the upper bed tend to be coarser grained. These two limestone beds lie about 250 feet (75 m) below the top of the Bear Canyon Member.

In contrast, in an unpublished measured section of the Bear Canyon Member at the west end of Wallsburg Ridge (just 10 miles [16 km] to the west) that totaled about 9,200 feet (2,805 m) thick, Welsh found the stratigraphically highest limestone beds to be about 2,340 feet (713 m) below the top of the section. He similarly noted limestones at depths of about 1,300 feet (396 m) and 1,800 feet (549 m) below the top of the Bear Canyon Member in the West Daniels Land #1 well (south of Daniels Canyon in section 11, T. 5 S., R. 5 E.), in which the Bear Canyon Member is probably about 4,600 feet (1,402 m) thick. Thus, the limestone beds present in the Center Creek quadrangle are apparently absent at Wallsburg Ridge and possibly in the West Daniels Land #1 well, illustrating east-west facies changes that typify sedimentation along the eastern margin of the Oquirrh basin. These sections, and others in the region, point to the highly variable amount of sandstone in the Bear Canyon Member, with some areas apparently receiving greater clastic input from the nearby Uncompahgre uplift. The variable thicknesses also reflect the presence of a regional disconformity that separates Middle Pennsylvanian ((Desmoinesian) and Upper Pennsylvanian (Missourian) rocks (Welsh and Bissell, 1979).

Fusilinid zones of *Fusilinella, Wedekindellina*, and *Fusulina* place the Bear Canyon Member in the Atokan and Desmoinesian (Middle Pennsylvanian). The lithologies and fauna indicate that the Bear Canyon Member was deposited in a moderately deep shelf or shallow-marine basin. Limestone muds, common in the lower and middle parts of the member, were deposited in quiet water with a sparse fauna of benthonic bryozoa, few fusilinids, and chonetid and productid brachiopods. Periodically the lime muds were overwhelmed by influxes of arkosic sand from the Uncompahgre uplift and to a lesser extent from coarse carbonate debris and rounded quartz grains from sources outside or marginal to the basin. The carbonate debris probably washed in from the shallow Callville platform that covered the Emery High to the south and southeast (Welsh and Bissell, 1979).

Shingle Mill Limestone Member (IPosm): The Shingle Mill Limestone Member forms an important marker in an otherwise thick sequence of similar sandstones of the Bear Canyon and

Wallsburg Ridge Members. The Shingle Mill Limestone Member forms ledgy outcrops in the lower reaches of Daniels Canyon where it helps to define the form of the Daniels Canyon anticline. The member consists of two thick limestone intervals separated by about 200 feet (61 m) of sandstone. One or both of these limestones are commonly poorly exposed due to cover by talus and colluvium, as will be discussed below. The best exposures of these limestone beds are at the southeast-plunging nose of the anticline along a southwest-trending spur at the common border of section 1, T. 5 S., R. 5 E. and section 36, T. 4 S., R. 5 E. (figure 2). Good exposures are also in the NW1/4 section 36, T. 4 S., R. 5 E., and on southwest-trending spurs near the center of section 26, T. 4 S., R. 5 E.

Figure 2 near here

Along the nose of the Daniels Canyon anticline, the lower limestone interval is about 80 feet (24 m) thick. It consists of thin- to thick-bedded, medium-gray, variably silty limestone with common black chert nodules and stringers. It becomes coarser grained, more fossiliferous, and cliff-forming upward, where it grades into a yellowish-brown- and rounded-weathering, very thick-bedded, medium-grained, calcareous, quartz sandstone with low-angle cross-stratification. This sandstone interval is about 200 feet (61 m) thick and is overlain by an upper, cliff-forming limestone interval that is about 100 feet (30 m) thick. This upper limestone is fine grained, medium gray, with abundant black chert nodules and thin beds that make up 25 percent or more of the unit and impart a thin-bedded appearance to the cliffs. Fossils are uncommon in these beds in the Center Creek quadrangle, but Welsh notes that the upper limestone interval at

Wallsburg Ridge contains a benthonic fauna of *Chonetes, Marginifera, Dictyoclostus*, rhynchonellids, bryozoa, crinoids, and trochoid gastropods.

These two limestone intervals are also exposed in the NW1/4 section 36, NW1/4NE1/4 section 34, and SE1/4SW1/4 section 27, T. 4 S., R. 5 E. However, in sections 22 and 26, along the north flank of the anticline near the crest of Hogsback Ridge, map patterns show the Shingle Mill Limestone Member thins considerably. Here, possibly only the lower limestone interval is included in the map unit. Exposures on the north side of Hogsback Ridge are extremely poor, and we found no limestone outcrop or float north of the ridge crest.

Baker (1976) only included the upper limestone interval in the Shingle Mill Limestone in the Daniels Canyon and Wallsburg Ridge area. We include both limestone intervals in the Shingle Mill Limestone Member based on Welsh's correlation that shows the lower and upper limestone intervals are equivalent to the Jordan and Commercial Limestones, respectively, of the Oquirrh Mountains. The *Eowaringella* fusilinid zone is in the basal part of the lower limestone, the same position in which it is found at Middle Canyon in the Oquirrh Mountains and at South Mountain. In the Center Creek quadrangle, *Eowaringella* was collected from beds near the center of section 26, T. 4 S., R. 5 E. No fusilinids have been found in the upper limestone interval or in the Commercial Limestone. However, 225 feet (69 m) above this limestone interval at Wallsburg Ridge, Welsh recovered the Missourian fusilinid *Triticities* from lower Wallsburg Ridge Member strata. Baker (1976) collected fusilinids from Shingle Mill strata on the west side of Wallsburg Ridge, in section 5, T. 6 S., R. 4 E., that were initially misidentified as Desmoinesian in age, but that were later reclassified as earliest Missourian (Raymond C. Douglass, U.S. Geological Survey, written communication, January 28, 1981).

In an unpublished measured section at Wallsburg Ridge, about 8 miles (13 km) west of Daniels Canyon, Welsh measured about 1,145 feet (349 m) of Shingle Mill strata. He found the lower limestone is about 230 feet (70 m) thick, the middle sandstone unit about 500 feet (152 m) thick, and the upper limestone interval about 385 feet (117 m) thick. In the West Daniels Land #1 well, Welsh assigned about 110 feet (34 m) to the lower limestone, 140 feet (43 m) to the middle sandstone, and 260 feet (79 m) to the upper limestone. These measurements, and those cited above for exposures in Daniels Canyon, illustrate an eastward thinning of this early Late Pennsylvanian sequence.

Wallsburg Ridge Member (IPowr): The Wallsburg Ridge Member was named by Baker (1976) for a thick sequence of siliceous, slightly feldspathic sandstones exposed along the crest of Wallsburg Ridge, just west of the Center Creek quadrangle. In the Center Creek quadrangle, the Wallsburg Ridge Member forms steep, commonly densely vegetated, scree-covered slopes over much of the southern half of the quadrangle. Exposures, however, are few, and marker beds nonexistent, so that mapping of Wallsburg Ridge strata is limited to measuring bedding attitudes.

The Wallsburg Ridge Member consists of a monotonous sequence of yellowish-brown, fine- to medium-grained, well-indurated, siliceous sandstones that typically contain 2 to 5 percent feldspar. The sandstones are commonly finely laminated and cross-laminated in thick to very thick beds, and are barren except for uncommon trace fossils on some bedding planes. These sandstones are nearly everywhere highly fractured, and near faults brecciated, so that bedding is difficult to determine and attitudes surprisingly difficult to obtain. Low-angle cross-laminae commonly form large wedge-shaped sets up to tens of feet in length. Combined with poor exposures, measurements on such beds can easily give erroneous strikes and dips. The sandstones commonly have a conchoidal fracture and so look like true quartzite or orthoquartzite.

Interbedded with these feldspathic sandstones are a few thin, silty and sandy limestones. Welsh noted five such beds in his unpublished measured section of Wallsburg Ridge, and over 30 such beds in correlative strata in the Oquirrh Mountains. These calcareous beds contain a benthonic fauna of *Caninia*- (rugosa-) type and *Syringpora*-type corals, fusilinids, and disarticulated crinoid columns.

In the upper reaches of Center Canyon, in the NW1/4SE1/4NW1/4 section 15, T. 5 S., R. 6 E., Wallsburg Ridge strata contain a ledge-forming, clast-supported conglomerate of possibly turbidite origin. The clasts are subangular to subrounded, both siliceous and calcareous sandstone up to 3 feet (1 m) in diameter set in a sandy calcareous matrix. Several thin limestone beds and an intraformational limestone conglomerate are exposed on the south-facing hillside in the SE1/4SE1/4SW1/4 section 34, T. 4 S., R. 6 E.

In his unpublished measured section at Wallsburg Ridge, about 8 miles (13 km) west of Daniels Canyon, Welsh measured about 5,200 feet (1,585 m) of Wallsburg Ridge strata, but noted that due to difficulty in obtaining accurate strike and dip measurements, the section thickness may be off by 10 percent. The West Daniels Land #1 well penentrated a nearly complete sequence of 4,150 feet (1,265 m) of the Wallsburg Ridge Member; however, strata there dip about 25 degrees southwest so that the stratigraphic thickness of the member is about 3,700 feet (1,128 m). Correlative strata in the Oquirrh Mountains are approximately 6,500 feet (1,982 m) thick, again illustrating the thinning of strata towards the eastern margin of the Oquirrh basin. Baker (1976) collected Missourian to Virgilian (Late Pennsylvanian) fusilinids from

Wallsburg strata at Wallsburg Ridge.

Granger Mountain Member: The lower part of the Granger Mountain Member is exposed southwest of State Highway 40 where it can be divided into two informal map units: a lower limestone unit and an upper, much thicker unit of interbedded sandstone and siltstone. To the west at Wallsburg Ridge, Welsh measured about 10,250 feet (3,125 m) of Granger Mountain strata, but only about the lower 2,500 feet (762 m) are present in the Center Creek quadrangle. Baker (1976) assigned just 7,300 feet (2,226 m) to the Granger Mountain Member at Wallsburg Ridge.

Lower unit (Pogl): The lower unit consists of two ledge- and cliff-forming limestone intervals of about equal thickness separated by a middle, somewhat thicker, slope-forming siltstone interval. Collectively, these limestones form an important marker in a vast thickness of Pennsylvanian and Permian sandstones and siltstones. The limestones are best exposed at the mouth of Parker Canyon and along the nose and west flank of the Big Hollow syncline. The limestones are medium to very thick bedded, medium gray, fossiliferous, and contain few thin, discontinuous beds and nodules of black chert. The limestones contain abundant *Schwagerina*-type fusilinids characteristic of the Early Permian (Wolfcampian), common bryozoans and rugose and syringporid corals, and uncommon crinoid stems and brachiopods. The middle siltstone interval consists of yellowish-brown, calcareous siltstone with few thin limestone interbeds.

Map patterns indicate that the lower Wolfcampian limestone unit thins to the west, from about 500 feet (152 m) thick at Parker Canyon on the east limb of the Big Hollow syncline to about 300 feet (91 m) thick on the west limb. These limestones are not present at Wallsburg Ridge about 5 miles (8 km) to the southwest.

Upper unit (Pogu): The upper unit consists of the Freeman Mountain sandstone facies and Curry Peak siltstone facies and forms densely vegetated slopes with remarkably few exposures. At Wallsburg Ridge, west of the quadrangle, Welsh measured six Freeman Mountain sandstone units totaling 6,350 feet (1,936 m) interbedded with about 3,900 feet (1,189 m) of Curry Peak siltstone. These interbedded relations and poor exposures preclude mapping the units separately in the Center Creek quadrangle. About the only good exposures in the quadrangle are on the southwest-trending spur in the SW1/4 section 14 and the SE1/4 section 15, T. 5 S., R. 5 E.

The Freeman Mountain sandstone facies consists of yellowish-brown, blocky weathering, medium- to thick-bedded, commonly bioturbated, fine- to medium-grained, normally calcareous, feldspathic sandstone. These sandstones contain small amounts of pyrite, which is oxidized to goethite in outcrop. Both vertical burrows and tracks parallel to bedding planes are common. A few beds of pebble-size, subangular clasts indicate debris flows interbedded with the finer grained sandstones. Uncommon beds contain reworked crinoid and fusilinid clasts that weather out to leave pits on the surface. The sandstones are less siliceous than the Pennsylvanian sandstones, and weather to more rounded, less fractured exposures.

The Curry Peak siltstone facies consists of laminated to thin-bedded, pyritic, commonly bioturbated, dark-gray siltstone with common ripple cross-stratification. In thin section, the siltstones show discontinuous films of inert organic material. In the Center Creek quadrangle, the best exposures of Curry Peak strata are immediately above the Wolfcampian limestone unit in the NW1/4SE1/4SE1/4 section 15, T. 5 S., R. 5 E.

Jurassic

Nugget Sandstone (Jn)

The Nugget Sandstone and correlative sandstone formations are renown as one of the world's largest coastal and inland paleodune fields, which covered much of what is now Utah and portions of adjacent states in the Early Jurassic. These sandstones are known too for their great thickness and uniformity. Except for a basal transitional zone and rare, thin, planar interdune deposits, they consist entirely of massively cross-bedded, fine- to medium-grained, commonly bimodal, quartz sandstone that weathers to bold, rounded cliffs.

An incomplete section of the Nugget Sandstone is exposed along the Lake Creek drainage at the north margin of the quadrangle. The Nugget Sandstone consists primarily of moderately well-cemented, well-rounded, frosted quartz grains. It is uniformly colored moderate reddish orange to moderate orange pink, although the upper part is generally white to very pale orange. Cementation is variably calcareous or siliceous, but the white upper part is commonly noncalcareous. The Nugget Sandstone is variably jointed, with the dominant joints trending northwest. Locally, sand grains eroded from Nugget outcrops are redeposited in small, thin sheets of eolian sand.

Along the north side of Lake Creek, the Nugget Sandstone forms a deeply dissected, near-dip slope. The base of the formation is not exposed in the Center Creek quadrangle, but dips apparently flatten to the north in the adjacent Francis quadrangle, so that the outcrop belt is wider than it appears it should be. The Nugget Sandstone is 1,306 feet (398 m) thick in the West Daniels Land #1 well; assuming a 15 degree westerly dip, the stratigraphic thickness of the Nugget is about 1,260 feet (384 m). Baker (1976) reported 1,500 feet (457 m) of Nugget Sandstone west of Charleston, about 16 miles (26 km) west of the Center Creek quadrangle. The Nugget Sandstone thins both to the north and east along the flanks of the Uinta uplift (Bryant, 1992).

The upper contact with the Twin Creek Limestone, the J-2 unconformity of Pipiringos and O'Sullivan (1978), is well exposed south of Lake Creek in the SE1/4NE1/4NE1/4 section 7 and the NW1/4NW1/4 section 8, T. 4 S., R. 6 E. The contact is marked by a prominent change in lithology, with dark-reddish-brown siltstone and jasperoid and brown to gray limestone of the Gypsum Springs Member of the Twin Creek Formation overlying the planated surface of the white, massively cross-bedded Nugget Sandstone.

Twin Creek Limestone (Jtc)

The Twin Creek Limestone is divided into seven members in northern Utah: in ascending order, these are the Gypsum Springs, Sliderock, Rich, Boundary Ridge, Watton Canyon, Leeds Creek, and Giraffe Creek Members (Imlay, 1967). The lower five members are each lithologically consistent and easily recognizable over a wide area, but when traced southward, the upper two members lose identity and grade into the Arapien Shale (Imlay, 1967, 1980; Sprinkel, 1982, 1994). Although individual members were not mapped due to scale and limited exposures, the lower five members can be identified in exposures south of Lake Creek. The best exposures are in the ravine in the NE1/4SE1/4NE1/4 section 7 and the NW1/4SW1/4NW1/4 section 8, T. 4 S., R. 6 E.

Sprinkel and Doelling (Utah Geological Survey, written communication, August 2, 1999) measured an incomplete section of 608 feet (185 m) of Twin Creek strata south of Lake Creek, and it is from their work that the following description is largely derived. The Gypsum Springs Member is 83 feet (25 m) thick and is marked at the base by a 10-foot-thick (3 m) slope-forming, dark-reddish-brown, sandy, calcareous siltstone with thick beds or boulder-size clasts of reddish- and yellowish-brown jasperoid. The jasperoid is overlain by about 16 feet (5 m) of medium-bedded, pinkish-brown, medium- to coarsely crystalline sideritic limestone with veinlets of siderite and calcite, which is in turn overlain by about 57 feet (17 m) of medium-bedded, brown to gray, dense, very fine-grained limestone with a conchoidal fracture. The Sliderock Member is 209 feet (64 m) thick and consists of brownish-gray, light-gray-weathering, slope-forming, thin- to medium-bedded, dense limestone with a conchoidal fracture, light-gray micritic limestone that weathers to pencil-like fragments, and medium-gray, dense, very fine-grained limestone with disarticulated *Pentacrinus* sp. columnals and fossil hash near the top. The Rich Member is 116 feet (35 m) thick and consists of medium-gray, thin- to medium-bedded, finely crystalline, ledge- and slope-forming limestone that weathers to pencil-like fragments and small chips, and very light-gray, very fine-grained calcareous sandstone with ripple marks. The Boundary Ridge Member is 145 feet (44 m) thick and consists of interbedded, red-brown siltstone and fine-grained sandstone and gray to brown sandy oolitic limestone and algal laminated limestone that forms reddish slopes. Only the lower 55 feet (17 m) of the Watton Canyon Member is exposed, but Sprinkel and Doelling estimate the member to be about 250 feet (76 m) thick. The Watton Canyon Member consists of yellowish-gray to medium-gray, oolitic limestone and dense, very fine-grained limestone, commonly with a conchoidal or rectilinear fracture.

The Twin Creek Limestone is Middle Jurassic (middle to late Bajocian to Callovian) in age and was deposited in warm, shallow-marine waters in the south end of a north-trending foreland basin during the first two major Mesozoic transgressive episodes in west-central North America (Imlay, 1967, 1980). In the Center Creek quadrangle, the Twin Creek Limestone is unconformably overlain by the Keetley Volcanics. Regionally, the Twin Creek Limestone is conformably overlain by the Pruess Sandstone and correlative strata (Imlay, 1980).

Cretaceous

Frontier Formation and Unnamed Shale Unit, Undifferentiated (Ku)

Strata herein assigned to the undifferentiated Frontier Formation and underlying unnamed shale unit (usage of Molenaar and Wilson, 1990) are exposed in widely separated exposures in the Center Creek drainage. Welsh was the first to recognize all but the easternmost of these generally poorly exposed, southwest-dipping beds in his unpublished mapping of the Center Creek quadrangle during the early 1980s. Lacking fossils or age estimates, he interpreted them as the early Tertiary Wasatch Formation. Hintze (1980) mistakenly showed one of these exposures as a window through upper-plate rocks, probably based on misidentification of the southwest-dipping beds as Mesozoic strata and the quartzite-boulder deposits as Oquirrh bedrock. Bryant (1992) first mapped the small, but critical, easternmost outcrop in the Center Creek quadrangle as undifferentiated Cretaceous strata and noted that it correlates with the Mesa Verde Formation and/or the Frontier Member of the Mancos Shale. As described below, we now believe these strata belong to the early Late Cretaceous unnamed shale unit that unconformably lies between the Mowry Shale and Frontier Formation on the south flank of the Uinta uplift, and possibly to the lower Frontier Formation itself.

Because outcrops are widely spaced and exposures generally poor, and due also to proximity to the Charleston thrust which truncates these strata, the vertical succession of beds in this outcrop belt is uncertain. The following are lithologic descriptions based on outcrop locations. The westernmost, and some of the best, exposures are in the south-central portion of section 19, T. 4 S., R. 6 E. In a small road cut in the SW1/4SE1/4SW1/4 section 19, Cretaceous beds are in fault contact with brecciated, northeast-dipping Wallsburg Ridge strata. These contorted Cretaceous beds consist of light-olive-gray to grayish-olive, calcareous mudstone with granule-size, irregularly shaped calcareous nodules; grayish-orange to dusky-yellow calcareous siltstone; and moderate-reddish-orange, calcareous, very fine-grained silty sandstone. For a distance of about 1,000 feet (305 m) northeast up the drainage, strata are very poorly exposed but appear to consist almost entirely of dark-reddish-brown mudstone and lesser siltstone that is mottled yellowish gray to light olive gray; these beds weather to reddish slopes with slightly swelling soils. Farther upslope, but down section, very pale-orange, grayish-orange, pale-red, and light-gray mudstone is interbedded with fine- to medium-grained, calcareous quartz sandstone that is deeply weathered and mostly covered by quartzite-boulder colluvium. This is in turn underlain by a thin, less than 1-foot-thick (0.3 m), light-gray limestone bed with poorly preserved, discontinuous algal stringers and lenses and veins of chalcedony that is exposed at the common border of the NE1/4NE1/4SW1/4 section 19 and the SE1/4NE1/4SW1/4 section 19. In the NE1/4NE1/4SW1/4 section 19 and the NE1/4SW1/4SE1/4 section 19, a grayish-orange-pink to pale-yellowish-orange, calcareous, medium- to thick-bedded, very fine- to fine-grained quartz sandstone and somewhat darker and coarser pebbly sandstone forms low ledges. The clasts are well-rounded quartzite, chert, and minor limestone pebbles to uncommon small cobbles. Most quartzite is light brown to white with fewer greenish-gray, red, or banded red and white clasts. Still farther up the drainage, reddish-brown mudstone is exposed in a small historical landslide in the SE1/4NE1/4SE1/4 section 19. Exposures in sections 28, 29 and 33 contain similar lithologies but lack the thin limestone interbed. No fossils were found in these beds, and four carefully collected samples from these outcrops failed to produce palynomorphs.

Fossiliferous strata were found, however, in outcrops in the south-central portion of section 34, T. 4 S., R. 6 E., the same outcrop that Bryant (1992) first located. Beds there form prominent, southwest-dipping strike ledges that stand in stark contrast to surrounding morainal deposits. A 6-foot-thick (2 m) oyster coquina limestone bed dips 32 degrees southeast. About 40 feet (12 m) of section is exposed stratigraphically below this oyster coquina in the main scarp of a small, historical slump. A well-cemented, very thick-bedded, very pale-orange to grayish-orange, fine-grained, noncalcareous sandstone at least 6 feet (2 m) thick is exposed at the base of the slope. This sandstone is overlain by a brownish-black, noncalcareous, soft shale that contains *Corbula* sp. bivalves, rare fish scales, and uncommon gastropods. Sample CC7899-1 from this bed yielded palynomorphs and dinoflagellate cysts indicative of a middle to late Cenomanian age (appendix). Only about the lower 3 feet (1 m) of this black shale interval is exposed, but it may be up to about 8 feet (2.5 m) thick. This shale bed is overlain by about 35 feet (11 m) of grayish-orange to moderate-yellowish-brown, calcareous, fine-grained silty sandstone with abundant gastropod and bivalve fossils that grades into the overlying oyster coquina (appendix). The brackish-water gastropod *Craginia turriformis* (Stephenson, 1952) indicates a Cenomanian age as it is replaced by *Craginia coalvillensis* in the Turonian (Kirkland, 1996). Additionally, *Pleurocardia* cf. P. "bisculpta" is a Cenomanian taxon (Kauffman and others, 1993), although it should be noted that P. "bisculpta" has only been described in an unpublished thesis (Geary, 1981) and is thus not a valid taxonomic name. Sample CC7899-2 from the middle of this interval also yielded palynomorphs and dinoflagellate cysts indicative of a middle to late Cenomanian age (appendix).

Early Late Cretaceous strata in the Center Creek quadrangle lie between well-studied outcrops near Coalville nearly 30 miles (48 km) to the north and at Currant Creek about 5 miles (8 km) to the southeast. Strata of these distant sections lie on either side of the Uinta uplift, where they are known by different names (Molenaar and Wilson, 1990). Because exposures in the Center Creek quadrangle lie south of the axis of the Uinta uplift, south-flank terminology is used in this report. The correlation of north and south flank strata is complicated by rapid facies changes and the absence of Cretaceous outcrops across the western projection of the Uinta uplift. Still, Molenaar and Wilson (1990) clearly show that the Frontier Formation thickens greatly to the northeast, from about 760 feet (232 m) at Currant Creek to 7,800 feet (2,378 m) near Coalville. They also note that the Frontier Formation in the Coalville area includes strata both somewhat older and younger than that of Frontier Formation strata on the south flank of the

Uinta uplift.

Our ages of middle to late Cenomanian correspond to the unnamed shale unit that unconformably overlies the Mowry Shale and unconformably underlies the Frontier Formation on the southwest flank of the Uinta uplift. The shale unit and bounding unconformities grade northwest into a conformable, much thicker section of the Chalk Creek Member of the Frontier Formation. Molenaar and Wilson (1990) note that the unnamed shale unit is probably marginal marine in origin and that the middle and upper parts contain increasing sandstone and pebbly sandstone westward. Bivalves and gastropods recovered from the south-central portion of section 34, T. 4 S., R. 6 E. are a mixture of brackish and shallow-marine taxa. Together with the absence of inoceramid bivalves and ammonites, which are restricted to open-marine conditions, these shelly beds are thought to indicate a subsaline environment, perhaps representing a large coastal bay (James I. Kirkland, Utah Geological Survey, written communication, August 4, 1999). Although the vertical succession of Cretaceous beds in the Center Creek quadrangle is unclear, the varied lithologies and faunal assemblages indicate that here brackish and shallow-marine sediments likely intertongue northwestward with fluvial and floodplain deposits equivalent to the distal Chalk Creek Member.

Cretaceous strata in the Center Creek quadrangle are incompletely exposed across an outcrop belt up to 3,500 feet (1,067 m) wide. They are unconformably overlain by the Keetley Volcanics and younger Quaternary deposits. Given an average 30 degree southwest dip, the maximum exposed thickness of Cretaceous strata in the Center Creek quadrangle is about 1,750 feet (534 m). An incomplete section of Cretaceous strata is about 2,500 feet (762 m) thick along the line of cross section A-A'.

Tertiary

Uinta Formation(?) (Tu?)

In the Center Creek quadrangle, the Uinta Formation(?) is a very poorly exposed, subrounded to rounded, pebble- to boulder-conglomerate that weathers to a residual boulder field. Because the clasts are almost entirely Oquirrh orthoquartzite and sandstone, it can be difficult to distinguish these deposits from poorly exposed Permian bedrock, which it unconformably overlies. Neither Baker (1976) nor Bryant (1992) mapped these deposits in the Center Creek quadrangle, although they did map apparently correlative deposits by different names a few miles to the south in the Twin Peaks quadrangle. In his unpublished mapping of the Center Creek, Charleston, Co-op Creek, and Twin Peaks quadrangles, Welsh suggests that these deposits are alluvial-fan facies of the Uinta Formation. Because only a small, poorly exposed portion of these deposits are in the Center Creek quadrangle, we have chosen to query the name pending further studies. Based on map patterns, only the lower 350 feet (107 m) of the formation is present in the Center Creek quadrangle. The Uinta Formation is Eocene in age (Dane, 1954).

Keetley Volcanics

The Keetley Volcanics are a sequence of late Eocene to Oligocene volcanic breccias, conglomerates, tuffs, lava flows, and intrusives that rest subhorizontally in a structural saddle between the Wasatch Range and Unita Mountains. The Keetley Volcanics are regionally divided into three lithologic units: a basal unit of fine-grained tuff, lapilli tuff, thin lahar deposits, and volcaniclastic sandstone and conglomerate at least locally deposited in a lake; a middle, thick sequence of volcaniclastic conglomerates and breccias; and an upper unit of lava flows (Leveinen, 1994; Bryant, 1992). Keetley strata are andesite and rhyodacite by field classification, but chemically range from trachyandesite and latite to silica-poor rhyodacite (Bromfield and others, 1977; Hanson, 1995; Feher, 1997; Vogel and others, 1997).

The Keetley Volcanics lie at the east end of the east-west-trending, 28-mile-long (45 km) Wasatch intrusive belt. As recently described by John (1987, 1989), Hanson (1995), Feher (1997), and Vogel and others (1997), several Tertiary intrusives are in the high-potassium, calc-alkaline rocks of the Wasatch intrusive belt. From west to east these include three phaneritic stocks (Little Cottonwood, Alta, and Clayton Peak), five porphyritic stocks (collectively known as the Park City porphyries), the Park Premier porphyry, and the Indian Hollow plug. With the exception of the slightly older, more mafic Clayton Peak stock, the silica content of the plutons generally increases to the west (Hanson, 1995), and the depth of emplacement increases to the west, from less than 0.6 mile (less than 1 km) for the porphyritic Park Premier and Indian Hollow intrusions to about 6.5 miles (11 km) for the phaneritic Little Cottonwood stock (John, 1987, 1989). The entire belt is between 33.5 and 36.6 million years old except the Little Cottonwood stock, which is 30.5 $\pm$ 0.5 Ma (Vogel and others, 1997). Both the Park Premier porphyry - which consists of five granodiorite to rhyodacite or dacite porphry intrusions and is the center of a several-square-kilometer area of hydrothermal alteration and precious-metal mineralization (Willes, 1962) - and the Indian Hollow plug - a volcanic neck which is surrounded by a radial dike swarm - intrude coeval Keetley strata (Bromfield, 1968; Woodfill, 1972; Hanson, 1995).

The Keetley Volcanics are similar to the eastern stocks (and the Alta stock) of the Wasatch intrusive belt with respect to emplacement ages and chemical composition (Leveinen, 1994; Hanson, 1995; Feher, 1997). Potassium-argon ages of biotite or hornblende from Keetley flows range from 32.7 $\pm$ 1.0 to 36.4 $\pm$ 1.3 Ma (Crittenden and others, 1973; Bromfield and others, 1977). Lower Keetley tuffs near Peoa contain early Oligocene vertebrates (Nelson, 1972). The Indian Hollow plug and Park City porphyries may be the source of most of the Keetley Volcanics (Bromfield, 1968; Woodfill, 1972; Bryant, 1992; Leveinen, 1994; Hanson, 1995; Feher and others, 1996; Feher, 1997). Hanson (1995) suggested that volcanic activity in the Wasatch intrusive belt began with intrusion of the Clayton Peak stock followed by eruption of the Keetley Volcanics and emplacement of the Park Premier stock and Indian Hollow plug. Finally, the Alta stock and then Little Cottonwood stock were emplaced.

Most Keetley clasts contain 15 to 25 percent hornblende and 25 to 35 percent plagioclase phenocrysts as major phases with minor biotite and clinopyroxene (Leveinen, 1994; Feher, 1997). Hanson (1995) and Feher (1997) noted that Keetley strata exhibit a wide range in chemical composition. Feher (1997) noted that compared to other well-documented calc-alkaline rocks, the Keetley Volcanics do not follow typical calc-alkaline chemical trends nor do they follow simple crystal fractionation or assimilation paths. She suggested that the complex Keetley chemistry may be due to processes involving multiple magmatic sources.

The Keetley Volcanics are in excess of 1,500 feet (500 m) thick north of Heber City (Bryant, 1992; Leveinen, 1994). In the Center Creek quadrangle, map patterns suggest that the Keetley Volcanics are locally in excess of 2,500 feet (762 m) thick. In the Center Creek quadrangle just south of Lake Creek, the Keetley Volcanics unconformably overlie Nugget and

Twin Creek strata. To the south in the Center Creek drainage, Keetley strata unconformably overlie Cretaceous and Oquirrh Formation strata. The Keetley Volcanics were deposited in an area of considerable pre-Keetley topography (Boutwell, 1912; Forrester, 1937, O'Toole, 1951; Woodfill, 1972; Feher, 1997).

Tuffaceous unit (Tkt): With one exception, the tuffaceous unit is present only north of Center Creek where it is nearly everywhere covered by colluvium and residual debris from the overlying quartzite-boulder unit and so is very poorly exposed. Test pits excavated by others in the NW1/4 section 13, T. 4 S., R. 5 E. show that the tuffaceous unit is at least locally covered by quartzite-boulder colluvium in excess of 7 feet (2 m) thick. Even so, soils developed on the tuffaceous unit tend to be white and poorly drained. The following description is based on just a handful of road-cut exposures in the SE1/4 section 13 and the NE1/4 section 24, T. 4 S., R. 5 E., and in the SW1/4SW1/4NW1/4 section 19, T. 4 S., R. 6 E., and two natural exposures in the SE1/4SW1/4NE1/4 section 19 and the NE1/4NW1/4SW1/4 section 20, T. 4 S., R. 6 E.

Road cuts in sections 13 and 24 reveal very light-gray, light-olive-gray, and light-brownish-gray, very fine-grained tuffaceous mudstone with uncommon, medium-sand-size biotite flakes. The small exposure in section 19 is light-olive-gray to yellowish-gray, fine-grained lapilli tuff with granule-size altered pumice fragments and similarly colored, medium- to coarse-grained, tuffaceous and pebbly sandstone with subangular quartzite clasts. The two natural exposures immediately underlie the quartzite-boulder unit, about 600 to 800 feet (183-244 m) above these road-cut exposures. They consist of both fine- and coarse-grained tuff and tuffaceous sandstone.

Deposits mapped in the lower reaches of Clegg Canyon consist of white to pinkish-gray to very pale-orange, thick- to very thick-bedded, moderately cemented, calcareous, tuffaceous sandstone and matrix-supported pebbly sandstone. The clasts are subangular to subrounded, white, calcareous and tuffaceous mudstone rip-up clasts and Oquirrh Formation orthoquartzite. The best exposures are in the SE1/4 section 8, T. 5 S., R. 6 E.

The tuffaceous unit appears to pinch out against Twin Creek strata in the northeast corner of the Center Creek quadrangle, in the W1/2 section 8, T. 4 S., R. 6 E. The nature of this apparent pinchout is uncertain, but it appears to be at least in part fault controlled based on offset of the Nugget Sandstone and Twin Creek Limestone. It may also reflect abrupt thinning of lower Keetley strata over a paleohigh of Twin Creek and Nugget strata, or erosion of the tuffaceous unit prior to deposition of the volcanic breccia of Coyote Canyon.

Quartzite-boulder unit (Tkq): The quartzite-boulder unit forms a coarse, clastic wedge that thins to the northeast in the Center Creek quadrangle. Because it lacks volcanic clasts, the unit contrasts sharply with the enclosing tuffaceous and volcaniclastic units of the Keetley Volcanics. The quartzite-boulder unit consists of two distinct but unmapped facies. The vast majority of the unit forms slopes covered by subangular to subrounded, pebbles to boulders of Oquirrh Formation orthoquartzite and uncommon limestone derived from the Charleston allochthon to the southwest. Two areas, however, contain Mesozoic clasts probably derived from the north and northwest.

The quartzite-boulder unit is nowhere well exposed, but it tends to form broad benches above colluvial-covered slopes of the tuffaceous unit. Few, small, consolidated outcrops of the quartzite-boulder unit were found in the Center Creek quadrangle. Clasts at the surface are commonly fractured so that the deposits appear more angular than they actually are. The quartzite-boulder unit locally contains large, brecciated blocks of Oquirrh Formation orthoquartzite up to 200 feet (61 m) in length. One block is at the common border of sections 20 and 29, T. 4 S., R. 6 E., about 1,100 feet (335 m) west of the east section line. The other block is in the NW1/4SE1/4NE1/4SE1/4 section 18, T. 4 S., R. 6 E. These large blocks are 1 mile (1.6 km) or more northeast of upper-plate strata and suggest a steep mountain front was present during Keetley time.

On the drainage divide between Lake Creek and Center Creek, in the NE1/4SE1/4 section 18, T. 4 S., R. 6 E., SE1/4 section 12, T. 4 S., R. 5 E., and the SW1/4 section 7, T. 4 S., R. 6 E., the quartzite-boulder unit consists principally of subangular to subrounded clasts of Thaynes Limestone (Early Triassic), Nugget Sandstone (Early Jurassic), clasts possibly from Park City (Permian), Woodside (Early Triassic), and Twin Creek (Middle Jurassic) strata, and locally orthoquartzite clasts derived at least in part from the Oquirrh Formation. Limestone clasts are typically rounded and volcanic clasts appear to be lacking. Boulders up to 10 feet (3 m) in diameter are present. These clasts were probably derived from the north and northwest. Similar clasts are present in the basal volcanic breccia of Coyote Canyon.

The contact with the volcanic breccia of Coyote Canyon appears sharp, and corresponds to the first appearance of volcanic clasts. The lower contact, with the tuffaceous unit, is difficult to determine in most areas. Where the quartzite-boulder unit forms broad benches, the contact is marked by a change in slope, with the quartzite-boulder unit forming steeper slopes.

The quartzite-boulder unit gradually decreases in elevation toward the north, but it also appears to drop abruptly across two west-trending drainages. One of these drainages straddles the common boundary of sections 18 and 19, T. 4 S., R. 6 E., across which the quartzite-boulder unit is dropped down about 400 feet (122 m) to the north. The unit is also dropped down about 200 feet (61 m) across the northwest-trending drainage that passes through the NE1/4 section 18, T. 4 S., R. 6 E. That the quartzite-boulder unit appears to be stepped down to the north suggests the presence of a pair of unrecognized faults, possible paleotopographic influences, or structures associated with a possible northwestward continuation of inferred sackungen along the crest of the ridge between the Lake Creek and Center Creek drainages.

Much of the area between the Center Creek and Lake Creek drainages herein mapped as the quartzite-boulder unit is misidentified on previous geologic maps (Baker, 1976; Hintze, 1980; Bryant, 1992) as Oquirrh strata, probably because of a predominance of orthoquartzite clasts. Bryant (1992) first mapped some of these deposits as an Oligocene-Eocene quartzite conglomerate and correlated them with similar deposits along the south flank of the Uinta Mountains. A zircon from an interbedded tuff in apparently correlative beds near Red Creek Mountain, about 12 miles (20 km) east-southeast of the Center Creek quadrangle on the southwest flank of the Uinta Mountains, has a fission-track age of 44.9 $\pm$ 2.1 Ma (Bryant and others, 1989).

Volcanic breccia of Coyote Canyon (Tkb): The volcanic breccia of Coyote Canyon, named by Bromfield and others (1970) for exposures at Coyote Canyon north of Heber City, is widely exposed on the drainage divide between Center Creek and Lake Creek. It is also present in the Center Creek drainage and in fault blocks at the east end of Hogsback Ridge. This unit consists principally of volcaniclastic boulder deposits that grade upward into coarse volcanic breccias. These deposits generally form slopes with abundant volcanic clasts, and in the Center Creek quadrangle, good exposures are restricted to road cuts. Limited bedding attitudes and interpretation of aerial photographs show that the volcanic breccia of Coyote Canyon dips gently north, toward the inferred source of the volcanic debris.

The basal part of the volcanic breccia of Coyote Canyon locally contains subrounded to rounded Oquirrh-like orthoquartzite clasts, as well as clasts from the Nugget, Thaynes, Woodside, and Park City(?) Formations. Such clasts become rare immediately upsection, where deposits consist almost entirely of coarse volcaniclastic boulder deposits (figure 3). These deposits grade upward into rhyodacitic to andesitic tuff breccias and coarse volcanic breccias. We identified a single marker bed in the northeast part of the quadrangle. It is a ledge-forming, gray- to red-weathering, andesitic flow breccia about 20 feet (6 m) thick.

Figure 3 near here.

At the east end of Hogsback Ridge, the volcanic breccia of Coyote Canyon locally contains abundant orthoquartzite and uncommon limestone clasts, thus suggesting that these deposits represent the basal part of the unit. Deposits in the Mud Spring and Cold Spring areas are thin and identified only by the occurrence of rounded volcanic cobbles and boulders. Soils developed on these deposits tend to be a deeper, richer brown compared to soils developed on Oquirrh Formation strata, and dessication cracks show that they exhibit a slight shrink-swell potential. On the ridge east of the Hogsback enclosure, orthoquartzite clasts predominate and volcanic clasts are rare. Near the center of section 3, T. 5 S., R. 6 E., about 2,000 feet (610 m) north of the south section line at an elevation of about 9,200 feet (2,805 m), a well-cemented, calcareous, subrounded, clast-supported, pebble to boulder conglomerate is exposed that consists of Oquirrh Formation orthoquartzites and uncommon limestones. Bedding is uncertain but probably subhorizontal. This orthoquartzite conglomerate may represent a tongue of the underlying quartzite-boulder unit described above, or may represent a younger, late Tertiary boulder deposit. Mapping in the adjacent Heber Mountain quadrangle may resolve this uncertainty.

The volcaniclastic deposits of the lower part of the volcanic breccia of Coyote Canyon probably represent reworked debris flows (Leveinen, 1994). These deposits lack gas-escape structures, bombs, and welded or aggultinated clasts, and do not show facies associations typical of lag-fall breccias or other co-ignimbrite breccias (Leveinen, 1994).

Keetley Volcanics, undifferentiated (Tku): We mapped, but did not assign a subunit name to, a low hill of Keetley Volcanics north of Lake Creek in the northwest corner of the quadrangle. The deposits are poorly exposed and contain a mixed clast assemblage of subrounded volcanic and orthoquartzite pebbles to boulders. The deposits are about 80 feet (24 m) thick in the Center Creek quadrangle. The deposits may belong to the volcanic breccia of Coyote Canyon, but they are at a topographically lower elevation than such deposits to the south. Future mapping in the adjacent Francis quadrangle may resolve the stratigraphic position of these deposits.

Alluvial Deposits (Ta)

We mapped a single exposure of moderately sorted, unconsolidated, sand- to boulder-size sediment of uncertain, probable late Tertiary age at the northwest end of Hogsback Ridge. This deposit lies 1,300 feet (396 m) above the floor of Daniels Canyon and contains subrounded volcanic and Oquirrh Formation orthoquartzite boulders to about 10 feet (3 m) in diameter. Baker (1976) mapped this deposit as a Tertiary intrusive, and assumed that the orthoquartzite boulders were imbedded in the "plug," although he admitted uncertainty in that interpretation. The size of the clasts and their bimodal composition strongly supports a debris-flow or reworked debris-flow origin for this deposit. The deposit could belong to the basal part of the volcanic breccia of Coyote Canyon, which also typically contains a mixed clast assemblage, but its isolation precludes confident correlation. These deposits cap Hogsback Ridge and are up to a few feet thick.

Quaternary and Tertiary

Alluvial-Fan Deposits (QTaf)

Alluvial-fan deposits of uncertain Quaternary to late Tertiary age are present in Daniels Canyon and south of the mouth of Center Creek canyon. The deposits in Daniels Canyon are generally 800 to 1,500 feet (244-457 m) above Daniels Creek where they were deposited in the broad, ancestral paleovalley of Daniels Canyon (figure 4). These alluvial-fan deposits consist almost exclusively of poorly sorted, locally derived, clay- to boulder-size sediment that forms a moderately sloping apron on the flanks of the Oquirrh highlands to the south. On the south side of Daniels Canyon, near and northwest of Boomer Canyon, the clasts consist entirely of subangular Oquirrh Formation orthoquartzites and rare limestone. Deposits in the SW1/4 section 35, T. 4 S., R. 5 E. are locally underlain by a poorly exposed, calcareous, coarse-grained, pebbly sandstone with orthoquartzite and deeply weathered tuffaceous clasts. These deposits probably represent channel deposits that were buried by alluvial-fan deposits. The alluvial-fan deposits can look remarkably similar to Oquirrh bedrock and unmapped regolith, but are distinguished by their slightly more diverse assemblage of Oquirrh Formation orthoquartzites and sandstones than typical bedrock exposures, and by their subtle geomorphic expression. Deposits between Clegg and Center Canyons contain mixed orthoquartzite and volcanic clasts and may belong to the quartzite-boulder unit or the lower part of the volcanic breccia of Coyote Canyon. These deposits range up to about 50 feet (15 m) thick.

Figure 4 near here

Old alluvial-fan deposits southwest of the mouth of Center Creek canyon are compositionally and morphologically similar to those on the south side of Daniels Canyon. These deposits appear to overlie the volcanic breccia of Coyote Canyon.

Quaternary

Alluvial Deposits

Old alluvial deposits (Qao): We mapped a single exposure of moderately sorted sand and pebble to small-boulder gravel in the lower reaches of Daniels Canyon that lies about 300 to 400 feet (91-122 m) above the valley floor. These deposits contain subrounded orthoquartzite and limestone clasts. The lower part of the deposit contains subrounded, calcareous, light-brown, medium- to coarse-grained, pebbly and tuffaceous sandstone with subangular to subrounded orthoquartzite clasts that are probably derived from the lower, tuffaceous unit of the Keetley Volcanics. The diversity and rounding of clasts suggests that these deposits are channel deposits derived from upstream sources. The deposits are probably less than about 20 feet (6 m) thick. Similar though less well-exposed deposits may be present beneath alluvial-fan deposits in the SW1/4 section 35, T. 4 S., R. 5 E. They are overlain by older alluvial-fan deposits that are composed of subangular orthoquartzite cobbles and boulders.

Valley-fill deposits (Qa_2, Qa_3): Valley-fill deposits in the eastern part of Heber Valley form a gently west-sloping surface little dissected by Daniels, Center, and Lake Creeks. These deposits consist of moderately sorted sand, silt, and pebble- to boulder-gravel that probably was deposited in braided streams choked with glacial outwash. Level 3 deposits are preserved as a low terrace above level 2 deposits at the eastern end of Heber Valley. Excavations for a Central Utah Project water facility just west of the Center Creek quadrangle revealed moderately well-developed secondary calcium carbonate in the upper part of the deposit (Stage II to II+ carbonate of Birkeland and others, 1991). The thickness of valley-fill deposits in the Center Creek portion of Heber Valley is uncertain but probably less than about 100 feet (30 m) (Peterson, 1970; Roark and others, 1991). Soil profiles reported by Sullivan and others (1988) suggest a latest

Pleistocene age for much of the alluvial surface in Heber Valley. The level 2 deposits likely contain Holocene sediment at least along the main drainages.

Stream-terrace deposits (Qat_2, Qat_3): We mapped stream-terrace deposits only along Daniels Creek and Lake Creek, where they form level to gently sloping alluvial surfaces above the modern floodplain. These deposits consist of moderately to well-sorted sand, silt, clay, and pebble to boulder gravel deposited principally in river-channel and floodplain environments. The deposits locally include small alluvial-fan and colluvial deposits adjacent to nearby steep slopes. The subscript denotes the relative age and height above the modern drainages: level 2 deposits are about 10 to 35 feet (3-11 m) and level 3 deposits are 35 to 60 feet (11-18 m) above modern drainages. Level 2 deposits along Lake Creek are generally 25 to 35 feet (7.5-11 m) above the modern drainage and are of probable glacial outwash origin. Stream-terrace deposits range up to about 45 feet (14 m) thick and are incised by alluvial deposits (Qal_1). Stream and terrace profiles constructed for Daniels Creek show that level 3 deposits may be correlative with, and in part older than, level 2 and 3 valley-fill deposits (Qa_2 and Qa_3) of the east end of Heber Valley.

Alluvial deposits (Qal_1): Alluvial deposits are present along Daniels Creek, Center Creek, and Lake Creek, the three principal drainages in the quadrangle. They consist of moderately to well-sorted sand, silt, clay, and gravel normally less than about 20 feet (6 m) thick. Alluvial deposits include river-channel and floodplain sediments and minor terraces up to about 10 feet (3 m) above current stream levels; small alluvial-fan and colluvial deposits too small to map separately are included in this map unit. Alluvial deposits are gradational with mixed alluvial and colluvial deposits.

Alluvial mud (Qam): Localized areas of alluvial mud are present on the surface and along the margins of ground moraine. These deposits, which accumulated in shallow depressions and swales following ice retreat, consist of dark-gray-brown clay and silt with abundant organic matter and are probably less than about 5 feet (2 m) thick.

Older alluvial-fan deposits (Qafo): Older alluvial-fan deposits form the deeply incised eastern margin of Round Valley in the southwest corner of the quadrangle, and they also form isolated surfaces high above the modern drainages of Daniels and Lake Creeks. The fan deposits consist of poorly to moderately sorted, boulder- to clay-size clasts derived from upgradient drainage basins and thus vary in clast composition. Deposits in Round Valley and Daniels Canyon consist of subangular Oquirrh Formation orthoquartzite and lesser limestone clasts. The deposits of Round Valley are displaced by the Round Valley fault, described later. The thickness of the older alluvial-fan deposits in the Round Valley portion of the Center Creek quadrangle is uncertain, but Roark and others (1991) reported that unconsolidated valley-fill deposits are generally less than 100 feet (30 m) thick throughout Round Valley. The older alluvial-fan deposits in Daniels Canyon cover a broad bench about 200 feet (61 m) above the modern valley floor (figure 2). The thickness of these deposits is uncertain due to colluvial cover at their downslope margins, but they may reach up to 100 feet (30 m) or more thick, thinning to a taper edge at their upslope margins. The upslope margin of the deposits in Daniels Canyon are commonly overlain by talus or mixed alluvial and colluvial deposits. Older alluvial-fan deposits in the Lake Creek drainage represent reworked material derived from the Keetley Volcanics, and consist of poorly sorted, boulder- to sand-size volcanic clasts in a dark-gray clayey matrix. These deposits overlie the Nugget Sandstone, and typically grade downslope into colluvium. The thickness of these deposits is uncertain but is probably similar to the deposits in Daniels Canyon. Older alluvial-fan deposits are probably middle to early-late Pleistocene in age.

Level 2 alluvial-fan deposits (Qaf_2): Level 2 alluvial-fan deposits are best developed in the Center Creek drainage and along the eastern margin of Heber Valley; smaller deposits are also found in the Daniels Creek drainage. These inactive alluvial-fan deposits form moderately incised, gently sloping surfaces that lie a few tens of feet above modern depositional surfaces. They consist of poorly to moderately sorted clay- to boulder-size sediments derived from upgradient drainage basins. The deposits probably range up to about 50 feet (15 m) thick. Along the eastern margin of Heber Valley, these deposits are characterized by moderately well-developed secondary calcium carbonate in their upper part (Stage III carbonate development of Birkeland and others, 1991) and they appear to be truncated by valley-fill deposits (Qa_2 and Qa_3) of Heber Valley. Level 2 alluvial-fan deposits thus predate the valley-fill deposits, the latter of which are believed to represent Pinedale-age glacial outwash deposited between about 30 and 12 ka. Level 2 alluvial-fan deposits are late Pleistocene in age.

Alluvial-fan deposits (Qaf_1): Active, isolated alluvial fans are common throughout the quadrangle. They consist of poorly to moderately sorted clay- to boulder-size sediments deposited principally by debris flows at the mouths of active drainages. These fans are active depositional surfaces, although somewhat older sediments may be present at depth. Most modern alluvial-fan deposits are probably less than 40 feet (12 m) thick and are Holocene in age.

Artificial Deposits (Qf)

Artificial fill consists principally of local borrow material used in the construction of small stock and retaining ponds throughout the Center Creek quadrangle. Most of the larger structures in the Center Creek and Lake Creek drainages were built to raise the level of existing small ponds already present on pre-existing morainal topography. We mapped only the larger fill deposits, although fill is common in "built-up" areas throughout the quadrangle.

Colluvial Deposits (Qc)

Colluvial deposits consist of poorly to moderately sorted, clay- to boulder-size, locally derived sediment deposited by slope wash, soil creep, and debris flows on moderate slopes. Colluvium is common on most slopes in the quadrangle, but is only mapped where deposits are thick and extensive enough to conceal large areas of bedrock. These deposits locally include talus and mixed alluvial and colluvial deposits that are too small to be mapped separately. Colluvial deposits range up to about 30 feet (9 m) thick.

Glacial Deposits (Qgb?, Qgp)

Deposits associated with late Pleistocene glaciation are present in the Lake Creek and Center Creek drainages. Ground moraine consisting of lodgment till, ablation till, and glaciofluvial deposits is present in both drainages above an altitude of 6,600 feet (2,013 m). The till is widespread on the valley floors and consists of poorly sorted, non-stratified, heterogenous mixtures of clay, silt, sand, gravel, cobbles, and boulders. Clasts are subangular to well rounded and include, in order of decreasing abundance, volcanic lithologies, orthoquartzite, sandstone, and limestone. Relative clast composition varies locally, reflecting differences in source rocks. The relative abundance of fine-grained matrix also varies locally, as does the degree of consolidation; the lodgment till is typically somewhat overconsolidated as a result of being deposited directly beneath active glacial ice, and is thus more compact than the ablation till. Locally, ice-thrust bedrock blocks up to several tens of feet in length may be present. Glaciofluvial deposits are present locally. Although similar in overall composition to the till, glaciofluvial deposits typically exhibit crude stratification and better sorting.

Glacial geomorphology in the Lake Creek and Center Creek drainages is represented by a variety of features. Hummocky ground moraine distinguished by numerous shallow closed depressions, many of which contain ponds or lakes, is common between altitudes of 7,000 and 7,600 feet (2,135-2,318 m). Local residents have constructed dikes adjacent to many of these depressions to increase the volume of impounded water (Witts Lake and Jones Reservoir, for example, in section 10, T. 4 S., R. 6 E.). Broad cirques are present at the heads of the drainages, on the adjacent Heber Mountain quadrangle. The cirque at the head of the Lake Creek drainage is better developed than its Center Creek counterpart, probably because of differences in erodibility of the underlying bedrock. Lateral and end moraines are prominent in the Lake Creek drainage, and lateral moraines may be present in the Center Creek drainage. Especially notable are sharp-crested moraines on the north side of Lake Creek, indicating late-stage glacial activity. A narrow, lateral moraine-like ridge crosses section 5, T. 4 S., R. 6 E. on the north side of Lake Creek, and is cored by Nugget Sandstone and mantled with what we interpret to be bouldery ice-marginal deposits. This ridge, along with an anomalously steep and uniformly eroded slope of Nugget Sandstone on the south side of Lake Creek, seems to indicate a narrow tongue of ice extended down the Lake Creek drainage to an altitude of 6,400 feet (1,952 m).

The glacial deposits in the Lake Creek drainage may be associated with the two most recent glaciations in the greater Rocky Mountain region: the Pinedale and Bull Lake (Blackwelder, 1915). The Pinedale glaciation is generally thought to have occurred between 12 and 30 ka (Madole, 1986), although some Pinedale end moraines may be as old as 60 to 70 ka (Coleman and Pierce, 1979; Porter and others, 1983). The Bull Lake glaciation occurred between 130 and 155 ka (Pierce and others, 1976). Bryant (1992) mapped the Lake Creek deposits as till of Pinedale age, but other workers have suggested that Bull Lake deposits may also be present (G.C. Schlenker, Kleinfelder, written communication, 1996).

Relative criteria used to differentiate Bull Lake, or at least pre-Pinedale, deposits at the lowermost extent of the glacial deposits include degree of post-glacial ground modification, soil development, and degree of weathering of coarse-grained volcanic clasts. The Bull Lake(?) deposits (Qgb?) are morphologically subdued and have better developed surface drainage than the Pinedale deposits (Qgp). Incised stream-channel exposures of Bull Lake(?) till in the SW1/4SE1/4 section 4, T. 4 S., R. 6 E. display significant clay and secondary calcium-carbonate accumulations consistent with soil-development indices for B-horizon development in Bull Lakeaged till as described by Shroba and Birkeland (1983) (figure 5). Exposures in Pinedale deposits display consistently weak B-horizon development. Finally, coarse-grained volcanic clasts within Bull Lake(?) deposits are typically partly to completely grussified, whereas similar clasts in Pinedale deposits are typically intact. Relative morphologic expression and local superposition of deposits indicates multiple glacial advances during both periods of glaciation, but we did not differentiate deposits associated with individual glacial stades on the geologic map.

Figure 5 near here.

Based on topography and subsurface contact projections, the Bull Lake(?) deposits likely have a maximum thickness of 200 feet (61 m), and the Pinedale deposits likely have a maximum thickness of 150 feet (46 m). Pinedale deposits in the Center Creek drainage appear to be thinner than those in the Lake Creek drainage, and in several areas, Cretaceous and Pennsylvanian outcrops are surrounded by thin morainal deposits. No evidence for pre-Pinedale glacial deposits was observed in the Center Creek drainage.

The Lake Creek ground moraine is largely derived from the Keetley Volcanics and is susceptible to landsliding. Hylland and Lowe (1995) interpreted a large part of the moraine area as a deep-seated landslide complex; detailed mapping, however, indicates areas that probably have not undergone post-glacial mass movement. Historical landsliding has been concentrated along the steeply incised banks of Lake Creek. The Center Creek ground moraine is also derived in part from the Keetley Volcanics, as well as from low-strength Cretaceous rocks, and so is also susceptible to landsliding. Although Bryant (1992) mapped the Center Creek Quaternary deposits as landslide deposits, soil texture and surface morphology in at least their lower extent suggest a glacial origin. However, the ground moraine thins to the east (up the valley), and differentiating moraine from landslide deposits is difficult due to scant exposures and extensive vegetative cover.

Mass-Movement Deposits

Landslide deposits (Qmso, Qmso?, Qmsy, Qmsh): We grouped landslides into older (Qmso, Qmso?), younger (Qmsy), and historical (Qmsh) landslides based on degree of preservation of characteristic features, similar to the classification proposed by McCalpin (1984). Historical landslides are characterized by hummocky topography, numerous internal scarps, chaotic bedding, and evidence of historical movement, such as tilted trees, very fresh scarps, and damaged roads, utilities, or other structures. Younger landslides are similar in character and occurrence as historical landslides, but landslide features such as scarps and slide blocks are morphologically less distinct as a result of weathering and erosion. Landslide features of older landslides are morphologically subtle or indistinguishable, and some deposits are queried.

The largest landslides in the Center Creek quadrangle involve the Keetley Volcanics and are characterized by a subdued morphology characteristic of older mass movements (Qmso). Based on the degree of preservation of characteristic landslide features, most of these mass movements probably occurred as rotational slumps in the late Pleistocene. Younger (including historical) landslides are also typically characterized by rotational slump, although translational movement or flow also occur locally.

We mapped numerous historical landslides, some of which had not previously been reported. Most historical landslides in the Center Creek quadrangle involve glacial till, the Keetley Volcanics, or Cretaceous strata, as well as colluvial and residual sediments derived from these units. Most of these landslides probably formed during the unusually wet years of the early 1980s, and some show signs of continued movement.

Talus deposits (Qmt): Talus consists of locally derived material deposited principally by rock-fall processes on and at the base of steep slopes. These deposits consist of very poorly sorted, angular boulders and lesser fine-grained interstitial sediments. Talus is widespread over bedrock units in the Center Creek quadrangle, especially the Oquirrh Formation, but we mapped only the larger, more prominent deposits. These deposits are characterized by angular boulder fields that lack vegetation and range up to about 30 feet (9 m) thick.

Mixed-Environment Deposits

Alluvial and colluvial deposits (Qac, Qaco): We mapped mixed alluvial and colluvial deposits along secondary drainages and larger swales. These deposits consist of poorly to moderately sorted, clay- to boulder-size, locally derived sediment modified by both alluvial and colluvial processes. Mixed alluvial and colluvial deposits (Qac) are generally less than 20 feet (6 m) thick, whereas older, inactive and deeply incised deposits (Qaco) are probably less than 40 feet (12 m) thick.

<u>Residual and colluvial deposits (Qrc):</u> Mixed residual and colluvial deposits obscure bedrock throughout much of the quadrangle, but are mapped principally where they are extensive enough to conceal large areas of bedrock and bedrock contacts. Such areas commonly correspond to north-facing, densely vegetated slopes. These deposits consist of poorly to moderately sorted, clay- to boulder-size, locally derived sediment derived from in-situ weathering and modified by colluvial processes. Mixed residual and colluvial deposits range up to about 15 feet (5 m) thick.

Stacked-Unit Deposits

<u>Colluvium over undifferentiated Cretaceous strata (Qc/Ku)</u>: Cretaceous strata are generally poorly exposed in the Center Creek quadrangle. They are commonly concealed by colluvial and lag deposits derived from the quartzite-boulder unit of the Keetley Volcanics, although local topography and soils indicate that Cretaceous strata are present at shallow depth. This colluvial cover varies from a few feet to about 10 feet (3 m) thick. We mapped this stacked unit because of the importance of Cretaceous bedrock in deciphering the structural history of the region, and because Cretaceous strata are prone to landslides.

STRUCTURE

Regional Setting

The Center Creek quadrangle lies in a structural and topographic saddle between the Uinta Mountains and the Wasatch Range. The Uinta uplift is a 160-mile-long (250 km) west-trending belt of mostly Middle Proterozoic rocks, and major movements on the uplift occurred in late Paleocene and early Eocene time and continued into Oligocene time (Bryant and Nichols, 1988). The Uinta uplift projects westward into the Cottonwood arch, in the central Wasatch Range, which exposes in part correlative Early, Middle, and Late Proterozoic rocks that were uplifted principally in the Neogene. These uplifts divide the Sevier orogenic belt into two structural segments marked by abrupt changes in stratigraphy within allochthons and by differences in the age of deformation and amount of thrust displacement (see, for example, Bradley and Bruhn, 1988).

The Center Creek quadrangle lies on the southern side of this uplift, and also straddles the Charleston thrust fault, which bounds the northeastern edge of the Charleston allochthon. The allochthon was emplaced during the late Early Cretaceous and early Late Cretaceous at the height of the Sevier orogeny in central Utah (Bryant and Nichols, 1988). Constenius (1996) described the extensional collapse of the Sevier orogenic belt during a middle Eocene to early Miocene episode of crustal extension. In this region, this gravitational collapse is recorded by the Deer Creek detachment fault and sediments deposited in a series of half grabens superimposed on the Charleston allochthon. Subsequent Basin and Range extension and magmatism overprinted much of this earlier phase of extension (Constenius, 1996).

Charleston Thrust Fault and Deer Creek Detachment Fault

The Charleston thrust fault bounds the northeast flank of the Charleston allochthon (Baker, 1976; Bryant, 1992), but is nowhere well exposed in the Center Creek quadrangle. We believe the fault trends southeast up the Center Creek drainage where it places the Pennsylvanian Wallsburg Ridge Member over southwest-dipping early Late Cretaceous strata. In the Center Creek quadrangle, emplacement of the Charleston allochthon can only be dated as post-middle to late Cenomanian (early Late Cretaceous), but exposures to the east along the correlative Strawberry thrust show an emplacement age of Turonian to Campanian (middle Late Cretaceous) (Bryant and Nichols, 1988).

Southeast of Crooked Creek, the Charleston thrust fault is wholly concealed by morainal deposits in the Center Creek drainage, whereas to the northwest, the fault is mostly concealed by a variety of alluvial, colluvial, and mass-movement deposits. The Charleston thrust is exposed, however, in a small road cut in the SW1/4SE1/4SW1/4 section 19, T. 4 S., R. 6 E. There, brecciated Wallsburg Ridge orthoquartzite is juxtaposed against multi-hued mudstone and siltstone of likely early Late Cretaceous age. Farther northwest, the thrust fault is concealed by tuffaceous deposits of the lower Keetley Volcanics.

As mapped here, the trace of the Charleston thrust differs from that of previous workers. Baker (1976) inferred that the thrust is buried under Keetley strata about 1 to 2 miles (1.5-3 km) north of where we now know it to be, probably because he did not recognize Cretaceous strata in the Center Creek drainage. Bryant (1992) did map Cretaceous beds in the upper reaches of the Center Creek drainage, and so correctly placed the thrust there, but he missed correlative beds along strike to the northwest; thus, he too showed the thrust under Keetley strata nearer to the mouth of Center Creek. Our mapping shows that the Charleston thrust places the Pennsylvanian

Wallsburg Ridge Member over early Late Cretaceous strata along its entire length in the middle and upper reaches of the Center Creek drainage; it is concealed under Keetley Volcanics at the mouth of the Center Creek drainage. Outcrop patterns of Mesozoic strata in the northwestern corner of the Center Creek quadrangle suggest that the thrust may cut down-section to the northwest, perhaps placing Wallsburg Ridge strata over Late Jurassic or Early Cretaceous strata under the eastern portion of Heber Valley. Such a trend indicates that the Charleston thrust ramps up-section from west to east and from south to north. Thus, we interpret the thrust as a sidewall decollement ramp in this area.

The position of the Charleston thrust is constrained in the Placid Oil Company West Daniels Land #1 well, and in part by a seismic line that crosses part of the Center Creek quadrangle between the mouths of Daniels Canyon and Center Creek canyon. Our interpretations of the West Daniels Land #1 well differ somewhat from those of Sprinkel (1994), who reported that the Charleston thrust places the Manning Canyon Shale (Mississippian) over the Arapien Shale (Jurassic) at a depth of 10,920 feet (3,329 m). We believe that the interval enclosing the Charleston thrust is more complex. Geophysical logs and rock cuttings from the West Daniels Land #1 well show a 110-foot-thick (34 m) interval of very pale-orange orthoquartzite at a depth of 11,420 to 11,530 feet (3,482-3,515 m) that we believe to be the Tintic Quartzite caught between the Charleston thrust fault and the Deer Creek detachment fault. Such a relationship is present to the west at Deer Creek Reservoir about 7 miles (11 km) west of the well (Baker, 1976), and in the Aspen Grove quadrangle (Baker, 1964). In the West Daniels Land #1 well, the Charleston thrust thus places a sliver of the Cambrian Tintic Quartzite over a nearly complete section of the Twin Creek Limestone.

Interpretation of beds immediately above the Tintic Quartzite remains equivocal. Well logs and cuttings reveal about 800 feet (244 m) of highly brecciated, very fine-grained limestone and shale. Doug Sprinkel (Utah Geological Survey, verbal communication, November 8, 1999) reported difficulties in drilling this interval, where shales apparently flowed into and repeatedly bridged the hole. The American Stratigraphic Company log for the hole shows a 15-foot-thick (5 m) bed of anhydrite at a depth of about 11,010 feet (3,357 m), near the middle of this brecciated interval; geophysical logs suggest that the bed is impure, and we found no anhydrite in the well cuttings. Unpublished palynomorph data from this well show a low-diversity spore assemblage of abundant *Lycospora* spp. and rare *Punctatisporites* spp. and *Denososporites* spp. that suggest a Mississippian(?) to earliest Pennsylvanian age for at least the upper part of this brecciated interval. The lower half of the brecciated interval yielded little palynological data. Sprinkel (1994) thus reasonably interpreted this interval as the Manning Canyon Shale over the Arapien Shale. Coauthor Welsh, however, believes that this interval is intensely fractured Bridal Veil Limestone Member of the Oquirrh Formation, not the Manning Canyon Shale, but admits uncertainty about the apparent anhydrite, which is unknown in either Pennsylvanian or Mississippian strata of the Oquirrh basin. While the identification of strata in this interval remains uncertain, inferred duplexes in Mississippian strata under the flanks of the Big Hollow syncline (see cross section A-A') also suggest the presence of Manning Canyon strata in the well. Cross section A-A' thus shows the upper part of the Manning Canyon Shale bounded by the Deer Creek detachment. The Deer Creek detachment is believed to be substantially parallel to bedding in the Manning Canyon Shale, as it is farther west (Baker, 1964). The anhydrite and enclosing strata may represent a thrust splay in Jurassic strata at the base of the Deer Creek detachment.

The Deer Creek detachment was probably emplaced following gravitational collapse of the Sevier orogenic belt during a middle Eocene to early Miocene episode of crustal extension (Constenius, 1996). Because the detachment does not appear to cut the Keetley Volcanics in the Center Creek quadrangle, most of the extensional back sliding probably occurred in the Eocene.

Allochthonous Rocks

Allochthonous rocks of the upper plate of the Charleston thrust are found in the southern portion of the quadrangle where they are folded into the paired Daniels Canyon anticline and the Big Hollow syncline. The Daniels Canyon anticline, the general form of which was first mapped by Baker (1976), is best defined by the outcrop expression of the Shingle Mill Limestone. The anticline plunges southeast, and at the mouth of the canyon, the axis of the fold lies just north of State Highway 40. When traced to the southeast, bedding attitudes show the axis climbs up to the crest of Hogsback Ridge in the vicinity of Mud Spring. The anticline appears to die out farther southeast. The crest of the anticline is broken by two steeply dipping normal faults that trend parallel to the axis of the fold and create a horst along the anticlinal axis. The southwestern fault has a displacement of about 1,200 feet (366 m) and the northeastern fault a displacement of about 900 feet (274 m) near the nose of the anticline at cross section A-A'. The Big Hollow syncline, named by Welsh for exposures at Big Hollow in the adjacent Charleston quadrangle, is best defined by outcrops of the lower Wolfcampian limestone unit of the Oquirrh Formation. The syncline plunges gently southeast, roughly parallel to the Daniels Canyon anticline. These fold axes trend parallel to the Charleston thrust fault, as might be expected here if the Charleston thrust is a sidewall decollement ramp.

In the southeast portion of the quadrangle, between Clegg Canyon and the crest of Hogsback Ridge, the Charleston allochthon is cut by several north- to northwest-trending, mostly down-to-the-west normal faults. The faults are identified principally by down-dropped blocks of Keetley Volcanics that are preserved in a small graben and a few half grabens. The displacement on the largest of these faults is about 1,000 feet (305 m) or perhaps slightly more. This fault system is believed to be linked with an inferred down-to-the-west normal fault that trends through the lower reaches of the Center Creek drainage. At this latter locality, the middle quartzite-boulder unit of the Keetley Volcanics is about 1,000 feet (305 m) lower in elevation on the west side of Center Creek than it is to the east of this drainage. In the southeastern corner of the quadrangle, dip reversals in Wallsburg Ridge strata suggest the presence of additional faults or folds, but poor exposures and lack of marker beds preclude mapping such structures.

Half grabens superimposed on the Charleston-Nebo allochthon show that 3 to 4 miles (5-7 km) of extension occurred on the sole thrust during the late Eocene to early Miocene (Royse, 1983; Reiss, 1985; Houghton, 1986; Constenius, 1995), and Constenius (1996) reported they may record as much as 12 miles (20 km) of extension. Some of this inferred extension probably occurred on the north- to northwest-trending, down-to-the-west normal fault described above. In the Center Creek quadrangle, there is no evidence of post-Keetley relaxation along the trace of the Charleston thrust itself.

In the middle reaches of Boomer Canyon, upper Wallsburg Ridge and lower Wolfcampian limestone strata show a marked change in the strike of beds. East of Boomer Canyon beds strike northeast, whereas to the west they strike northwest. Although exposures are limited, no faults were identified in this area. These anomalous dips may reflect a subsidiary, oblique fold on the nose of the Daniels Canyon anticline.

The Charleston allochthon is bounded on the east by the Strawberry thrust and on the south by the Nebo thrust. The Charleston and Strawberry thrusts are structurally linked beneath a cover of syn- and postorogenic strata and were emplaced during the Sevier orogeny, in the early Late Cretaceous, with the last major movement immediately southwest of the Uinta Mountains in the Campanian (Bryant and Nichols, 1988). The Nebo thrust is a separate splay that was emplaced earlier, in the late Early Cretaceous and early Late Cretaceous (Bryant and Nichols, 1988). Estimates of eastward-directed displacement of the Charleston allochthon, which was emplaced at the height of the Sevier orogeny in central Utah, range up to about 40 miles (64 km) (Crittenden, 1961), but cutoff relations between hanging-wall and footwall strata of the Thaynes Formation suggest a displacement of about 19 miles (31 km) (Gallagher, 1985).

Autochthonous Rocks

In the Center Creek quadrangle, exposed autochthonous rocks include the Nugget Sandstone, Twin Creek Limestone, and early Late Cretaceous beds that belong to an unnamed shale unit and probably to the lower Frontier Formation. These beds dip uniformly southwest towards the Charleston thrust and are mostly concealed by the Keetley Volcanics and younger Quaternary deposits. The simple homoclinal dip reflects the quadrangle's location at the southwestern margin of the Uinta uplift. Bryant and Nichols (1988) reported that the first upward movement of this part of the Uinta uplift probably occurred in the late Campanian to early Maastrichtian (late Late Cretaceous), but that the major movement occurred in the late Paleocene and early Eocene and continued into the Oligocene. Because the latest Eocene to Oligocene Keetley Volcanics rest subhorizontally over these autochthonous strata in the Center Creek quadrangle, most movement of the Uinta uplift in this immediate area must be pre-latest Eocene in age. In the Center Creek quadrangle, 25 to 35 degrees of tilt of autochthonous beds can be attributed to uplift of the Uinta Mountains. Presumably, this uplift tilted the Charleston thrust fault as well, which was already steeply dipping in this area as a result of its inferred position as part of a sidewall ramp.

A small, down-to-the-northeast normal fault offsets the Nugget/Twin Creek contact in the NW1/4 section 8, T. 4 S., R. 6 E. Displacement on this fault is less than about 20 feet (6 m). About 1 mile (1.6 km) to the southeast, a marker bed in the Keetley Volcanics shows a similar displacement. It is likely that these two breaks reflect displacement along the same fault. We infer a second down-to-the-northeast normal fault, with a displacement of at least 100 feet (30 m), immediately to the west to account for apparent offset of the Nugget/Twin Creek contact and the absence of the tuffaceous unit of the Keetley Volcanics east of this inferred fault.

Heber Valley and Round Valley

Heber and Round Valleys are two of the southernmost back valleys (fault-bounded valleys east of the Wasatch fault zone) first described in some detail by Gilbert (1928). In plan view, Heber Valley resembles an irregular triangle that is 8 to 10 miles (13-16 km) long on a side; only the eastern part of the valley lies within the Center Creek quadrangle. The valley is somewhat anomalous in that its margins are sinuous and lack evidence of late Quaternary, basin-bounding faults (Bromfield and others, 1970; Sullivan and others, 1988; Bryant, 1992). Sullivan and Nelson (1983) trenched a 2,000-foot-long (600 m), 3- to 39-foot-high (1-12 m) linear scarp at the entrance to Big Hollow on the south side of the valley and concluded that it formed as an erosional feature. They also suggested that bedrock facets between embayments along the south margin of the valley may have formed by lateral stream migration and erosion of brecciated Oquirrh bedrock by the Provo River and its tributaries. Similar escarpments are cut in level 2 alluvial-fan deposits both to the west and east of the mouth of the Center Creek drainage (in the central parts of sections 11 and 15), and, although they have not been trenched, we believe that these too are erosional in nature.

However, inferred Heber Valley bounding faults (Bryant, 1992) seem to be required to explain: (1) the depth of Heber Valley, which may have up to 790 feet (240 m) of basin fill (Peterson, 1970), (2) the depth of Daniels Canyon, and (3) the capture of the Keetley drainage by the Provo River in Heber Valley (Sullivan and others, 1988). Baker (1964, 1976) showed that the structural floor of Heber Valley lies at a lower elevation than its outlet, requiring that the valley be down-dropped along unmapped faults relative to its outlet. Sullivan and others (1988) summarized evidence that suggests Heber Valley may have been near its present relative level for the last several hundred thousand years even though the lower and probably the upper Provo Canyons have deepened considerably over the same time period. They suggested that a combination of mid-Tertiary extension and episodes of erosion and aggradation by the Provo River and its tributaries best explain the present topography of Heber Valley. The degree to which Basin and Range extension has overprinted earlier extensional structures of the valley is uncertain.

In contrast, Quaternary basin-bounding faults are easily recognized at Round Valley (Sullivan and others, 1988; Bryant, 1992). Round Valley is entirely within the Charleston allochthon, and the lack of mid-Cenozoic deposits there suggests that the valley developed after mid-Cenozoic reactivation of the Charleston thrust (Sullivan and others, 1988). The easternmost Round Valley fault cuts older alluvial-fan deposits in the extreme southwest corner of the Center Creek quadrangle. The resultant scarp is degraded and varies from about 50 to 80 feet (15-24 m) high depending on where it is measured. While the age of the most recent displacement on the Round Valley faults is not constrained, Hecker (1993) suggested that it is middle to late Pleistocene, based in part on comparison with the better studied Morgan fault.

ECONOMIC GEOLOGY

Aggregate

In the past, aggregate was quarried from a variety of alluvial and colluvial deposits in the Center Creek quadrangle. The Utah Department of Transportation Materials Inventories of Wasatch County (Utah State Department of Highways, 1966) contains basic analytical information on these inactive or abandoned deposits, which are shown on the map with a symbol. Alluvial deposits in the quadrangle at the eastern end of Heber Valley contain large amounts of moderately sorted sand and gravel.

Crushed stone is presently quarried from highly fractured Bear Canyon orthoquartzite at the mouth of Daniels Canyon, and a similar quarry in Wallsburg Ridge strata near the mouth of Center Creek canyon closed in the late 1990s. These quarries tap a virtually unlimited supply of highly fractured and brecciated Oquirrh sandstones. Because these sandstones are siliceous and generally only slightly feldspathic, they are classified as orthoquartzite. When crushed and screened, they provide a high-quality source of aggregate.

Oil and Natural Gas

Exploration for oil and gas in the Center Creek quadrangle resulted in the drilling of the Placid Oil Company West Daniels Land #1 wildcat well (API # 43-051-30014), which was spudded in 1982 and plugged and abandoned in 1983, in the NE1/4NW1/4NW1/4 section 11, T. 5 S., R. 5 E. The well is one of many drilled during the overthrust exploration boom of the late 1970s and early 1980s. The well was spudded near the top of the Wallsburg Ridge Member, encountered what we believe to be the Deer Creek detachment fault at a depth of about 11,420 feet (3,482 m) and the Charleston thrust at a depth of 11,530 feet (3,515 m), and reached a total depth of 17,322 feet (5,281 m) in the Weber Quartzite. The well was abandoned before reaching the intended target, a structure in Mississippian carbonates below the Charleston thrust, due to repeated problems believed to result from shales flowing into and bridging the hole at a depth of about 10,800 feet (3,293 m) (Doug Sprinkel, Utah Geological Survey, verbal communication, November 4, 1999). Oil shows were reported but not tested in Park City and Weber strata. A well drilled in 1950 near the mouth of Daniels Canyon, in the SW1/4NE1/4NE1/4 section 21, T.

4 S., R. 5 E., just west of the Center Creek quadrangle, was reported to have reached a depth of only 515 feet (157 m) (Hansen and Scoville, 1955). No other information is available for this well.

Ritzma (1975) described the Daniels Canyon oil-impregnated rock deposit (Chinese Wax mine) near Highway 40, about 4.5 miles (7 km) south of the Center Creek quadrangle. The mine was worked sporadically for 60 years or more beginning around 1900. The mine exploited a small deposit of black, viscous, waxy oil emplaced in brecciated Oquirrh (Freeman Mountain sandstone facies) strata. The oil probably migrated laterally into the brecciated zone from onlapping Tertiary rocks. No similar oil-impregnated rocks were observed in the Center Creek quadrangle.

Prospects

Despite the fact that correlative Oquirrh strata are in part host to the mineral deposits of the Bingham mining district 40 miles (65 km) to the west, and despite the proximity of the nearby Park City mining district, we observed no evidence of mineralization in Oquirrh Formation or other bedrock strata in the Center Creek quadrangle. No prospects were identified.

Geothermal Resources

The geothermal potential of the Center Creek quadrangle is unstudied and unknown, but thermal springs are present near Midway, on the west side of Heber Valley. These springs issue from several widespread, coalescing travertine and tufa mounds with water temperatures that range from 100 to 114 degrees Fahrenheit (38-46 ^{0}C) (Baker, 1968; Kohler, 1979; Blackett, 1994). Springs at the Mountain Spa and Homestead Resorts are used to heat a swimming pool and for therapeutic baths. Baker (1968) concluded that the water is meteoric, originating in the mountains to the northwest and emerging through fractures at Midway. The heat source is unknown, but is attributed to deep circulation (Baker, 1968).

Building and Ornamental Stone

The Nugget Sandstone has long been quarried in northern Utah as a source of building and ornamental stone. Quarries near the mouth of the Lake Creek drainage, at the east end of Heber Valley, still provide a reddish-orange, or “salmon” colored, fine- to medium-grained sandstone widely used in Utah for building and decorative work. The sandstone naturally splits into thin sheets and blocks along cross-bedding surfaces and joints. This sandstone was used for a number of historic buildings in Heber City.

WATER RESOURCES

The Center Creek quadrangle is within a continental climate zone (Richardson, 1976), and average annual precipitation is between about 20 and 30 inches (51-76 cm) (Baker, 1970). Most of this precipitation is associated with low-pressure storms between October and May, although significant precipitation also occurs in August during cloudburst storms. About half of the annual precipitation falls as snow in Heber Valley, whereas more than half falls as snow in the higher elevations (Richardson, 1976). Runoff and spring flow are concentrated in several perennial and numerous ephemeral stream channels within the quadrangle.

The surface- and ground-water resources in the Center Creek quadrangle have been evaluated as part of regional hydrogeologic studies in the area (Baker, 1970; Roark and others, 1991) and for classification of the Heber Valley valley-fill aquifer (Jensen, 1995; Lowe, 1995). The following information is largely compiled from these sources.

Lake Creek, Center Creek, and Daniels Creek flow across the quadrangle from southeast to northwest and are relatively major tributaries to the Provo River, located west of the quadrangle. Although perennial, these streams flow within Heber Valley only during winter and early spring; during the rest of the year, the streams are diverted at the valley margins for irrigation and flow through a series of canals and ditches. Daniels Creek is the largest of the three streams, having an estimated discharge of 15.6 cubic feet per second (0.44 m^3/s) (Hyatt and others, 1969). Estimated discharges of Lake and Center Creeks are 10.9 cubic feet per second (0.31 m^3/s) and 6.5 cubic feet per second (0.18 m^3/s), respectively (Hyatt and others, 1969). Surface water in the eastern Heber Valley area is calcium-bicarbonate type and is generally low in dissolved solids.

Ground water occurs in fractured bedrock and in the valley-fill aquifer of Heber Valley. The primary source of public water supplies for the community of Center Creek is spring water that discharges from bedrock. Jurassic sandstone and limestone yield calcium-magnesium-bicarbonate-type water having total dissolved solids (TDS) concentrations of less than 500 mg/L, and Tertiary volcanic rocks yield calcium-bicarbonate-type water having TDS concentrations of less than about 1,000 mg/L (Baker, 1970). Most water wells in the area draw from unconsolidated valley-fill sediments. The valley-fill deposits of eastern Heber Valley form a single, essentially homogeneous, unconfined aquifer. Depth to ground water is as shallow as 5 to 20 feet (1.5-6 m) below the ground surface at the eastern end of Heber Valley, and becomes deeper to the west. The valley-fill aquifer yields calcium-bicarbonate-type water having TDS concentrations of less than 500 mg/L (Baker, 1970).

GEOLOGIC HAZARDS

Geologic hazards are naturally occurring geologic processes that may present a danger to life and property, and are important factors to be considered prior to development. Hazards that exist in the Center Creek quadrangle include landsliding, stream flooding, alluvial-fan flooding, debris flows, shallow ground water, problem soil and rock, earthquakes, and radon. Hylland and others (1995) mapped geologic-hazard areas in western Wasatch County, including much of the Center Creek quadrangle, and discussed considerations for development in these areas.

Landslides

Several types of landslides exist within the Center Creek quadrangle, including shallow debris slides, deep-seated earth or rock slumps, and earth flows. The landslides typically occur in

Pleistocene glacial deposits, the Tertiary Keetley Volcanics, and Cretaceous strata, and colluvial and residual deposits derived from these units. Many of the landslides are prehistoric, but historical landslides are abundant in the Lake Creek and Center Creek drainages. Although dormant or inactive, prehistoric landslides pose a hazard in that they may become reactivated as the result of changes in ground-water conditions, seismic activity, or slope modifications resulting from erosion or development activity. An example of reactivation of a prehistoric landslide is provided by the Pine Ridge landslide in the NE1/4 section 9, T. 4 S., R. 6 E. (Ashland and Hylland, 1997). This deep-seated slump in Pleistocene glacial deposits underlies about 114 lots in the Timber Lakes Estates subdivision. An 11-acre (4.4 ha) section of the landslide reactivated sometime during the winter or early spring of 1985-86, resulting in damage to a cabin and formation of a main scarp up to 15 feet (5 m) high that crosses several vacant lots. Results of a preliminary geotechnical-engineering slope-stability study indicate the northern part of the Pine Ridge landslide, adjacent to the incised Lake Creek channel, may be marginally stable under static conditions, and that movement of the entire landslide could result from strong earthquake ground shaking at a time of high ground-water levels (Ashland and Hylland, 1997). Critical slope inclinations, which represent gradients above which landsliding has typically taken place under climatic conditions similar to the present, have been calculated by Hylland and Lowe (1997) for landslides in the Pleistocene glacial deposits and some of the bedrock units present in the quadrangle.

Two other types of mass movement may also be a hazard in the Center Creek quadrangle. The first type, rock fall, generally has not been a significant hazard because of a lack of source areas near residential areas. However, rock falls may occur locally below steep exposures such as road cuts, cliffs, or stream banks, and may be especially numerous during strong ground shaking accompanying earthquakes. Because of steep slopes adjacent to many areas along Highway 40, the rock-fall hazard is probably greatest in the Daniels Canyon area. The second type of mass movement is a class of ridge-top deformation features called “sackungen,” which are thought to result from large-scale, deep-seated gravitational spreading. Features ascribed to sackungen elsewhere in the United States and Europe (see, for example, Varnes and others, 1989; McCalpin and Irvine, 1995) are present on the divide between the Lake Creek and Center Creek drainages, in the S1/2 section 16 and N1/2 section 21, T. 4 S., R. 6 E., and include ridge-top troughs or grabens and uphill-facing scarps. Detailed study is needed to determine the origin of the sackungen in the Center Creek quadrangle, to verify whether these features are indeed sackungen or not, and to evaluate the hazard that may exist associated with differential movement across the sackungen landforms.

Stream Flooding

Stream flooding is typically associated with rapid spring snowmelt in the mountains and summer cloudburst rainstorms. Stream flooding can be a hazard in areas delineated by the Federal Insurance Administration (FIA) and the Federal Emergency Management Agency (FEMA) as 100-year flood plains as well as in minor drainages not delineated by the FIA or FEMA. Flood-hazard areas in minor drainages are shown in Hylland and others (1995) and generally correspond to areas of Holocene alluvium (Qal_1) deposited by floodwaters. In addition to flooding associated with natural alluvial processes, flooding may also result from the failure of a dam. There are nine small dams in the Lake Creek and Center Creek drainages that are considered high-hazard dams (Matthew Lindon, Utah Division of Water Rights, Dam Safety Section, written communication, 1996); the high hazard rating is based on dam size, reservoir volume, and the possibility of loss of life in the event of a dam failure (Lindon, 1992).

Alluvial-Fan Flooding and Debris Flows

Alluvial-fan flooding, characterized by little advance warning and unpredictable flow paths, is a hazard on Holocene alluvial fans (Qaf_1). The flooding typically occurs as a debris (hyperconcentrated) flood, which is a mixture of soil, organic material, and rock debris transported by fast-moving floodwaters (Wieczorek and others, 1983). Holocene alluvial fans can also be affected by debris flows, which occur when sediment and debris in the floodwaters create a muddy slurry much like wet concrete. Normal stream flow, debris floods, and debris flows form a continuum of sediment/water mixtures that grade into each other with changes in the relative proportion of sediment to water and with changes in stream gradient (Pierson and Costa, 1987). Debris floods contain 40 to 70 percent solids by weight, and debris flows contain 70 to 90 percent solids by weight (Costa, 1984). Debris floods and debris flows can be hazards in the stream channels above alluvial fans as well as on the fans themselves. Like normal stream flooding, debris floods and debris flows can result from intense precipitation during cloudburst rainstorms. Debris flows can also mobilize directly from landslides.

Alluvial-fan flooding and debris flows generally have not been significant hazards in the Center Creek quadrangle in historical time. However, a potential hazard exists on Holocene alluvial fans and in stream channels, especially if the vegetation in drainage basins is damaged by wildfire, grazing, or development.

Shallow Ground Water

Ground water is considered shallow when the water table is within 30 feet (9 m) of the ground surface (Hecker and others, 1988). In areas of unconsolidated surficial deposits, which is where most construction takes place, shallow ground water can present a flooding hazard to below-grade structures, especially if the ground water is within about 10 feet (3 m) of the ground surface. Other hazards associated with shallow ground water include inundation of landfills and waste dumps, flooding of wastewater-disposal systems, and ground-water contamination. Shallow ground water is present in Heber Valley, in the vicinity of the mouths of the Lake Creek and Center Creek drainages, and in localized areas in the upper Lake Creek and Center Creek drainages (Woodward and others, 1976; Hecker and others, 1988; Hylland and others, 1995). The tuffaceous unit of the Keetley Volcanics, and overlying residual and colluvial debris, appears to be poorly drained.

Problem Soil and Rock

Problem soils are surficial-geologic materials susceptible to volumetric change, collapse, subsidence, or dissolution that can cause engineering problems. Problem soils that may exist in the Center Creek quadrangle include collapsible soils, expansive soils, and organic soils.

Collapsible soils are loose, dry, low-density deposits that are susceptible to hydrocompaction, a phenomenon that causes a volume reduction or collapse when the soil is saturated for the first time following deposition (Costa and Baker, 1981). In Utah, collapsible soils are typically associated with alluvial-fan deposits (Mulvey, 1992), but some fine-grained colluvial or alluvial deposits may also have collapsible soils (Owens and Rollins, 1990). Collapsible soils are most likely to be found in areas underlain by Holocene alluvial fans containing clayey deposits.

Expansive soils are clay-rich, and can shrink and swell with changes in moisture content. When water is added to certain varieties of clay minerals (montmorillonite, in particular), the clay may swell by absorption of water between clay particles or into the crystal lattices that make up the individual particles (Tourtelot, 1974; Mulvey, 1992), causing the clay-bearing soil to expand. As the soil dries, the loss of water causes it to shrink. U.S. Soil Conservation Service maps indicate that soils with a moderate to high shrink-swell potential are present in the Lake Creek and Center Creek drainages (Woodward and others, 1976). Dessication cracks in clay-rich Cretaceous strata show that these rocks exhibit a slight shrink-swell potential.

Organic soils contain peat, which consists of accumulations of decomposed and disintegrated plant material. Peat is characterized by high void ratios and moisture contents, and therefore is susceptible to extreme reductions in volume that may include shrinkage, settlement, and compression (Bell, 1983). Post-glacial alluvial mud deposits (Qam) in the Center Creek quadrangle contain organic matter and could be subject to varying degrees of volume reduction.

Earthquake Hazards

The Center Creek quadrangle lies within the Intermountain seismic belt (Smith and Sbar, 1974), a generally north-south-trending zone of earthquake activity that bisects Utah. Many faults within this zone are active and capable of producing earthquakes, including the Wasatch fault, located about 20 miles (32 km) west of the quadrangle. Surface-faulting earthquakes resulting from movement on the Wasatch fault or other potentially active faults in the area could be of magnitude 6.5 or larger. In addition, smaller earthquakes that do not cause surface fault rupture (up to magnitude 6.5), and thus are not necessarily attributable to a mapped fault, could also cause damage and may occur anywhere in the area (Smith and Arabasz, 1991). Earthquake hazards in the quadrangle include ground shaking, surface fault rupture, and landsliding.

The Center Creek quadrangle lies within seismic zone 3 of the Uniform Building Code (UBC) (International Conference of Building Officials, 1997). Earthquakes of small to moderate size are not uncommon in western Wasatch County. A magnitude 4.7 earthquake with an epicenter about 3 miles (5 km) east of Heber City occurred on October 1, 1972, and caused minor damage associated with ground shaking in Heber City and the nearby communities of Midway and Wallsburg (Langer and others, 1979). Also, ground shaking from an earthquake on February 13, 1958, caused minor damage in Wallsburg, just west of the Center Creek quadrangle in Round Valley (Brazee and Cloud, 1960). Based on a maximum Modified Mercalli intensity of VI, this earthquake had a magnitude of about 5.0 (Arabasz and McKee, 1979; Hopper, 1988).

Earthquake ground motions are typically reported in units of acceleration as a fraction of the force (acceleration) of gravity (*g*). In general, the greater the acceleration or "*g*" force, the stronger the ground shaking and the more damaging the earthquake. National seismic-hazard maps developed by Frankel and others (1996; also U.S. Geological Survey, 1999) give probabilistic ground motions in terms of peak ground acceleration and 0.2-, 0.3-, and 1.0-second-period spectral accelerations having 10, 5, and 2 percent probabilities of exceedance in 50 years. Probabilistic ground-motion values applicable to rock sites in the middle of the Center Creek quadrangle are summarized in table 1.

Table 1. Probabilistic ground-motion values (in *g*) applicable to rock sites in the middle of the Center Creek quadrangle, Wasatch County, Utah. Data from U.S. Geological Survey (1999).

Abbreviations: PE, probability of exceedance; PGA, peak ground acceleration; SA, spectral acceleration.

	10% PE in 50 yr	5% PE in 50 yr	2% PE in 50 yr
PGA	0.15	0.21	0.32
0.2 sec SA	0.34	0.48	0.74
0.3 sec SA	0.30	0.42	0.63
1.0 sec SA	0.11	0.16	0.25

In some cases, earthquake ground motions can be amplified and shaking duration prolonged by local site conditions. Soft clayey soils and deep, sediment-filled basins, as well as thin gravelly soils over shallow bedrock, can amplify ground motions above the levels found in nearby rock. The amount of amplification varies with the frequency of the seismic waves. Recent theoretical studies have shown that shallow, "stiff" soils (for example, sand or gravel deposits present locally in Heber Valley) may amplify the higher frequency seismic waves that are most damaging to low-rise buildings (Adan and Rollins, 1993).

A surface-fault-rupture hazard is associated with the fault that cuts older alluvial-fan deposits (Qafo) in the extreme southwest corner of the quadrangle (plate 1). This fault is one of three normal faults bounding and within Round Valley, which lies mostly west of the Center Creek quadrangle. Information regarding the ages and recurrence intervals of movement on the Round Valley faults is lacking and detailed studies are needed. Sullivan and others (1986) speculated that the Round Valley faults may have been active in late Quaternary time, and Hecker (1993) estimated an earthquake surface-wave magnitude of M_s 6.5-6.75 associated with movement on one of these faults. Hylland and others (1995) show surface-fault-rupture special-study zones associated with the Round Valley faults and provide recommendations for hazard studies prior to development within these zones. Poorly understood Heber Valley bounding faults may also present a surface-fault-rupture hazard.

Landslides and rock falls are hazards likely to occur on steep slopes during an earthquake. Depending on prevailing ground-water and slope conditions and the severity of shaking, new landslides may form and pre-existing landslides may reactivate. Rock falls may be especially numerous beneath cliffs and road cuts that expose poorly consolidated bouldery deposits, or where boulders, such as glacial erratics, lie on sloping ground surfaces.

Indoor Radon

Radon (^{222}Rn) is an odorless, tasteless, and colorless radioactive gas that forms as a product of radioactive decay. Although outdoor radon concentrations never reach dangerous levels because air movement dissipates the gas, people can be subject to a radon hazard in buildings that have poor circulation. Health officials believe breathing elevated levels of radon over time increases a person's risk of lung cancer (National Council on Radiation Protection and Measurements, 1984; Samet, 1989).

Although radon is present in small concentrations in nearly all rocks and soils, several geologic factors control the radon hazard. The primary factor is the distribution of uranium-enriched rock and soil. Granite, metamorphic rocks, some volcanic rocks, and black, organic-rich shales are generally associated with indoor-radon hazards. Once uranium is present in rock or soil, other factors enhance or impede radon production and movement, including permeability and water saturation (Tanner, 1964, 1980; Barretto, 1975). A high permeability enhances radon movement by allowing the gas to diffuse through the rock or soil. Water saturation inhibits radon movement by filling pore spaces and restricting the flow of soil gas (Tanner, 1980).

Although indoor radon generally is not a major geologic hazard in the Center Creek quadrangle, combinations of geologic factors contributing to a potential hazard do exist locally, particularly in areas underlain by Tertiary volcanic rocks. As part of a statewide study of geologic conditions related to radon hazard, Black (1993) identified a moderate radon-hazard potential in all of the Center Creek quadrangle area except for Heber Valley, where the hazard potential is low due to shallow ground water. Indoor testing is the only reliable way to determine if a radon hazard exists (U.S. Environmental Protection Agency, 1992).

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Figure 1   Index map showing the Center Creek 7.5-minute quadrangle and surrounding area. Geologic maps of adjacent quadrangles are also shown; Bryant's (1992) 1:125,000-scale geologic map of the Salt Lake City 1^0x2^0 quadrangle covers all of these quadrangles.

Figure 2   Oblique aerial view of the south-facing slope of Hogsback Ridge in the lower reaches of Daniels Canyon. Note ledges of the Shingle Mill Limestone Member (IPosm) that are exposed on the southeast-plunging nose of the Daniels Canyon anticline. Older alluvial-fan deposits (Qafo) and talus, characterized by stone stripes, cover a mid-level bench and adjacent slopes carved into Oquirrh strata. Photograph taken in 1981.

Figure 3 Volcanic breccia of Coyote Canyon exposed in cliff face at head of cirque, section 22, T. 4 S., R. 6 E. Hammer is at intraformational contact between two thick debris-flow beds that fine upward.

Figure 4 Oblique aerial view to west of the late Tertiary erosional surface preserved above Daniels Canyon. Row Hollow, in the adjacent Twin Peaks quadrangle, is at the lower left of the photograph. Photograph taken in 1981.

Figure 5   White, pedogenic carbonate horizon developed in till, exposed in south slope of ravine in SW1/4SE1/4 section 4, T. 4 S., R. 6 E.; note hammer for scale. The north slope of this ravine exposes a moderately well-developed Bt soil horizon. Soil development suggests till may be of Bull Lake age.

APPENDIX

Spores, pollen, and microplankton analyses by Gerald Waanders, Consulting Palynologist

Sample number CC7899-1

Spores and pollen:		**Microplankton:**	
Araucariacites australis	(A)	*Aptea polymorpha*	(R)
Classopolis classoides	(A)	*Canninginopsis colliveri*	(R)
Deltoidopora spp.	(R)	*Florentinia cooksoniae*	(R)
Exesipollenites tumulus	(R)	Microforminifera linings	(R)
Liliacidites peroreticulatus	(R)	*Spiniferites ramosus*	(R)
Parvisaccites radiatus	(R)		
Rugubivesiculites reductus	(R)		
Taxodiaceae	(F)		
Tricolporopollenites granulocuneus	(R)		
Undifferentiated Bisaccates	(A)		

Organic recovery:	20% amorphous, 30% cuticular, and 50% woody
Age:	middle to late Cenomanian
Environment:	Nearshore marine, lagoonal, or estuarine

R = rare, < 6 specimens per slide; F = frequent, 6 to 15 specimens per slide; C = common, 16 to 30 specimens per slide; A = abundant, > 30 specimens per slide.

Sample number CC7899-2

Spores and pollen:		Microplankton:	
Araucariacites australis	(R)	*Canninginopsis colliveri*	(R)
Cicatricosisporites australiensis	(R)	*Circulodinium distinctum*	(R)
Cicatricosisporites brevvilaesuratus	(R)		
Classopolis classoides	(A)		
Deltoidopora spp.	(R)		
Exesipollenites tumulus	(R)		
Gleicheniidites senonicus	(F)		
Leptolepidites tenuis	(R)		
Liliacidites peroreticulatus	(F)		
Parvisaccites radiatus	(R)		
Rugubivesiculites reductus	(R)		
Taxodiaceae	(F)		
Tricolpites sp. A Nichols & Jacobson	(R)		
Undifferentiated Bisaccates	(R)		

Organic recovery: 5% amorphous, 15% cuticular, and 70% woody

Age: middle to late Cenomanian

Environment: Nearshore marine, beach, or deltaic

R = rare, < 6 specimens per slide; F = frequent, 6 to 15 specimens per slide; C = common, 16 to 30 specimens per slide; A = abundant, > 30 specimens per slide.

Molluscan taxa identified by James I. Kirkland, State Paleontologist, Utah Geological Survey

Molluscan taxa from sample locations CC7899-1 and CC7899-2:

BIVALVIA

Barbatia micronema (Meek, 1873)	B
Brachiodonte multilinigere (Meek, 1873)	B
Phelopteria dalli (Stephenson, 1936)	M
Crassostrea soleniscus (Meek, 1871)	B
Pleuriocardia n. sp. (P. Cf. "P. Bisculpta" Geary, 1981)	M
Dentonia leveretti (Cragin, 1893)	B
Corbula sp.	B-M

GASTROPODA

Craginia turriformis (Stephenson, 1952)	B
Levicerithium sp.	B
Gyrodes conradi (Meek, 1976)	M
Alifusus n. sp.	M

B = Brackish

M = shallow marine

QUATERNARY

Alluvial deposits

Qal_1 **Alluvial deposits** (Holocene) -- Moderately sorted sand, silt, and pebble- to boulder-gravel; includes river-channel and floodplain deposits, and terraces up to 10 feet (3 m) above current stream level; locally includes small alluvial-fan and colluvial deposits; 0 to 20 feet (0-6 m) thick.

$Qat_{2,3}$ **Stream-terrace deposits** (late Pleistocene) -- Moderately sorted sand, silt, and pebble- to boulder-gravel that forms isolated, level to gently sloping surfaces above modern drainages; deposited principally in river-channel and floodplain environments; subscript denotes relative age and height above modern drainage with level 2 deposits about 10 to 35 feet (3-11 m) and level 3 deposits 35 to 60 feet (11-18 m) above modern drainages; stream-terrace deposits are likely in part of glacial outwash origin; 0 to about 45 feet (0-14 m) thick.

Qam **Alluvial mud deposits** (Holocene to latest Pleistocene) -- Dark gray-brown clay and silt with organic matter; deposited in shallow depressions on the surface and along the margins of glacial moraine; 0 to 5 feet (0-2 m) thick.

$Qa_{2,3}$ **Valley-fill deposits** (late Pleistocene to Holocene) -- Moderately sorted sand, silt, and pebble- to boulder-gravel that forms floor of Heber Valley; moderately well-developed secondary calcium-carbonate in upper part of Qa_2 deposit (Stage II to II+ carbonate of Birkeland and others, 1991); subscript denotes height above modern drainage and relative age, although differences are minor; probably deposited as glacial outwash in braided channels; likely contains Holocene sediment at least along main drainages; probably less than 100 feet (30 m) thick.

Qao **Old alluvial deposits** (Pleistocene) -- Moderately sorted sand and pebble to boulder gravel; contains subrounded Oquirrh Formation orthoquartzite and limestone clasts, and pebbly tuffaceous sandstone cobbles from the Keetley Volcanics; single exposure mapped in lower reaches of Daniels Canyon where it is about 300 to 400 feet (91-122 m) above modern stream level; 0 to 20 feet (0-6 m) thick.

Qaf_1 **Alluvial-fan deposits** (Holocene) -- Non-stratified, poorly to moderately sorted, boulder- to clay-sized sediment deposited principally by debris flows at the mouths of active drainages; probably less than 40 feet (12 m) thick.

Qaf_2 **Level 2 alluvial-fan deposits** (late Pleistocene) -- Non-stratified, poorly to moderately sorted, boulder- to clay-sized sediment incised by active drainages; characterized by well-developed secondary calcium-carbonate in upper part of deposit (Stage III carbonate development of Birkeland and others, 1991) along southeast margin of Heber Valley; 0 to about 50 feet (0-15 m) thick.

Qafo **Older alluvial-fan deposits** (Pleistocene) -- Non-stratified, poorly to moderately sorted, boulder- to clay-sized sediment; deeply incised, locally in excess of 200 feet (61 m) above modern drainages; 0 to about 100 feet (0-30 m) thick.

Artificial deposits

Qf **Artificial fill** (Holocene) -- Fill used to create retaining ponds; consists principally of local borrow material; only larger fill deposits are mapped, although fill is common in "built-up" areas, many of which are shown on the topographic base map; thickness variable.

Colluvial deposits

Qc **Colluvial deposits** (Holocene) -- Poorly to moderately sorted, clay- to boulder-size, locally derived material deposited on moderate slopes; deposited by slopewash, soil creep, and debris flows; locally includes talus and alluvial deposits; 0 to 30 feet (0-9 m) thick.

Glacial deposits

Qgp **Glacial till** (late Pleistocene) -- Non-stratified, poorly sorted till consisting of heterogenous mixtures of clay, silt, sand, gravel, cobbles, and boulders; clasts are subangular to well rounded and primarily consist of volcanic rocks and orthoquartzite with minor sandstone and limestone; includes local glaciofluvial deposits; Pinedale age on the basis of moderate to sharp morainal topographic expression and weak soil development; estimated thickness 0 to 150 feet (0-46 m).

Qgb?

Glacial till (Pleistocene) -- Till of similar character as Qgp; possible Bull Lake age based on weathering of coarse-grained volcanic clasts, soil development, and relatively subdued morainal topographic expression; estimated thickness 0 to 200 feet (0-61 m).

Mass-movement deposits

Qmsh **Historical landslide deposits** (Holocene) -- Very poorly sorted, clay- to boulder-size, locally derived sediment deposited principally by rotational and translational downslope mass movement; characterized by hummocky topography, numerous internal scarps, chaotic bedding, and historical evidence of movement; slip surfaces occur in Cretaceous strata, Keetley Volcanics, glacial deposits and other Quaternary deposits; the slides themselves incorporate these units and overlying deposits; thickness highly variable.

Qmsy **Younger landslide deposits** (Holocene to latest Pleistocene?) -- Similar character and occurrence as Qmsh, but landslide features such as scarps and slide blocks are morphologically less distinct as the result of weathering and erosion; thickness variable, but may be as much as 75 feet (23 m) thick.

Qmso, Qmso?

Older landslide deposits (Pleistocene) -- Similar character and occurrence as Qmsy, but landslide features such as scarps and slide blocks are morphologically subtle or indistinguishable; includes large, deep-seated bedrock landslides; thickness variable.

Qmt **Talus deposits** (Holocene) -- Very poorly sorted, angular boulders and lesser fine-grained interstitial sediments; locally derived material deposited by rock fall on and at the base of steep slopes; characterized by angular boulder fields that lack vegetation; about 0 to 30 feet (0-9 m) thick.

Mixed-environment deposits

Qac **Alluvial and colluvial deposits** (Holocene) -- Poorly to moderately sorted, clay- to boulder-size, locally derived sediments deposited in swales and small drainages; generally less than 20 feet (6 m) thick.

Qaco **Older alluvial and colluvial deposits** (Holocene? to Pleistocene) -- Poorly to moderately sorted, clay- to boulder-size, locally derived sediments that form incised, inactive surfaces several tens of feet above modern drainages; 0 to about 40 feet (0-12 m) thick.

Qrc **Residual and colluvial deposits** (Holocene) -- Poorly exposed, poorly sorted, clay- to boulder-size, locally derived sediment; mapped principally on north-facing slopes where it supports dense vegetation and obscures bedrock contacts; 0 to about 15 feet (0-5 m) thick.

Stacked-units

Qc/Ku **Colluvium over undifferentiated Cretaceous strata** -- Colluvial veneer that mostly conceals underlying Frontier Formation and unnamed shale unit strata.

QUATERNARY AND TERTIARY

QTaf **Alluvial-fan deposits** (Pleistocene to Pliocene?) -- Poorly to moderately sorted, boulder- to clay-sized sediment; forms isolated remnants up to 1,500 feet (457 m) above Daniels Creek; deposits near and northwest of Boomer Canyon consist almost exclusively of subangular, locally derived Oquirrh Formation orthoquartzite clasts; deposits near Cummings Flat contain mixed orthoquartzite and volcanic clasts and may be part of the Oligocene Keetley Volcanics; 0 to about 50 feet (0-15 m) thick.

Ta **Alluvial deposits** (Pliocene?) -- Moderately sorted, unconsolidated, sand- to boulder-size sediment that caps the northwest end of Hogsback Ridge, about 1,300 feet (396 m) above Daniels Creek; contains mixed, subrounded Oquirrh orthoquartzite and Keetley volcanic clasts to 10 feet (3 m) in diameter; 0 to a few feet thick.

unconformity

OLIGOCENE-EOCENE

Keetley Volcanics

Tku **Keetley Volcanics, undifferentiated** -- Mapped north of Lake Creek in northwest corner of quadrangle; contains mixed assemblage of subrounded volcanic and orthoquartzite pebbles to boulders; may belong to the volcanic breccia of Coyote Canyon; exposed thickness about 80 feet (24 m).

Tkb **Volcanic breccia of Coyote Canyon** -- Thick sequence of volcanic conglomerate and breccia; clasts are andesite and rhyodacite by field classification but chemically range from trachyandesite and latite to silica-poor rhyodacite (Bromfield and others, 1977); volcanic conglomerate is abundant near the base and is interbedded and intertongues upward with coarse volcanic breccia; conglomerate locally contains orthoquartzite, sandstone, and limestone clasts, especially near base of unit; marker bed is a ledge-forming, gray- to red-weathering, andesitic breccia about 20 feet (6 m) thick; most deposits suggest a reworked debris-flow origin, although primary pyroclastic and flow deposits are present high in the section; published K-Ar ages from outside the quadrangle are 32.7 $\pm$ 1.0 to 36.4 $\pm$ 1.3 Ma (Crittenden and others, 1973; Bromfield and others, 1977); 0 to more than 1,400 feet (0-427+ m) thick.

Tkq **Quartzite-boulder unit** -- Unconsolidated to poorly consolidated, poorly to moderately sorted, subangular to subrounded, pebble to boulder conglomerate; consists principally of Oquirrh Formation orthoquartzite and rare limestone clasts and thins to northeast away from upper plate of Charleston thrust; clasts commonly fractured so deposits appear more angular than they actually are; locally contains blocks of brecciated quartzite up to 200 feet (61 m) in length; contains Mesozoic and Paleozoic (Nugget, Thaynes, Woodside, and Park City?) clasts to 6 feet (2 m) in diameter in SE1/4 section 12, T. 4 S., R. 5 E., and SW1/4 section 7 and SE1/4 section 18, T. 4 S., R. 6 E., suggestive of a northwest source; probably deposited in alluvial-fan environment shed principally to northeast off upper plate of Charleston thrust; 0 to about 450 feet (0-137 m) thick.

Tkt **Tuffaceous unit** -- Very light-gray to greenish-gray tuff and tuffaceous sandstone and pebbly sandstone; rarely exposed; forms slopes covered with quartzite-boulder unit colluvium; 0 to at least 720 feet (0- 220 m) thick.

unconformity

EOCENE

Tu? **Uinta Formation?** -- Very poorly exposed, subrounded to rounded, pebble- to boulder-conglomerate; clasts are principally Oquirrh Formation orthoquartzites; forms residual boulder field; only the lower 350 feet (107 m) exposed.

unconformity

CRETACEOUS

Ku **Frontier Formation and unnamed shale unit, undifferentiated** -- Interbedded mudstone, siltstone, sandstone, pebbly sandstone, and uncommon limestone; sandstone is medium to very thick bedded, very pale-orange to light-brown, calcareous, very fine- to medium-grained quartz sand; pebbly sandstone is coarser with well-rounded quartzite, chert, and limestone clasts to small cobble size; mudstone and siltstone are commonly mottled dark reddish brown and light olive gray and are slightly swelling; includes at least two limestone beds, one of which is probably less than one foot (0.3 m) thick light-gray limestone with algal(?) structures and stringers of chalcedony, and the other, which is a ledge-forming, 6-foot- (2-m-) thick oyster coquina; grayish-orange to moderate-yellowish-brown, fine-grained silty sandstone and brownish-black mudstone under oyster bed contain abundant gastropods and bivalves indicative of a Cenomanian age, uncommon fish scales, and a middle to late Cenomanian palynomorph and dinoflagellate assemblage; incomplete section about 2,500 feet (762 m) thick.

Kmm Mowry Shale -- subsurface only

CRETACEOUS AND JURASSIC

KJdcm

Dakota Sandstone and Cedar Mountain and Morrison Formations -- subsurface only

JURASSIC

Jsp Stump Formation and Pruess Sandstone -- subsurface only

Ja Arapien Shale – subsurface only

Jtc **Twin Creek Limestone** -- Five undifferentiated members, from youngest to oldest, are exposed: Watton Canyon Member (55 feet [17 m] exposed thickness) is yellowish gray to medium-gray, oolitic limestone and dense, very fine-grained limestone, commonly with a conchoidal or rectilinear fracture; Boundary Ridge Member (145 feet [44 m] thick) is interbedded, red-brown siltstone and fine-grained sandstone and gray to brown sandy oolitic limestone and algal laminated limestone that forms reddish slopes; Rich Member (116 feet [35 m] thick) is medium-gray, thin- to medium-bedded, finely crystalline, ledge- and slope-forming limestone that weathers to pencil-like fragments and small chips, and very light-gray, very fine-grained calcareous sandstone with ripple marks; Sliderock Member (209 feet [64 m] thick) is brownish-gray, light-gray-weathering, slope-forming, thin- to medium-bedded, dense limestone with a conchoidal fracture, light-gray micritic limestone that weathers to pencil-like fragments, and medium-gray, dense, finely crystalline to very fine-grained limestone with *Pentacrinus* sp. and fossil hash near the top; Gypsum Springs Member (83 feet [25 m] thick) is slope- and ledge-forming, dark-reddish-brown, sandy, calcareous siltstone, jasperoid, pinkish-brown sideritic limestone, and brown to gray, dense, very fine-grained limestone with a conchoidal fracture; maximum exposed thickness 608 feet (185 m). Measured by Doug Sprinkel and Hellmut Doelling (UGS unpublished data, June 22, 1999).

unconformity (J-2)

Jn **Nugget Sandstone** -- Moderate-reddish-orange to moderate-orange-pink, massively cross-bedded, poorly to moderately well-cemented, generally noncalcareous, well-rounded, fine- to medium-grained, frosted quartz sandstone; upper part is generally white to very pale orange; variably jointed; deposited in a vast coastal and inland dune field;

only upper part exposed; about 1,260 feet (384 m) thick in West Daniels Land #1 well.

TRIASSIC

TRa Ankareh Formation -- subsurface only

TRt Thaynes Formation -- subsurface only

TRw Woodside Shale – subsurface only

PERMIAN AND PENNSYLVANIAN

Ppc Park City Formation – subsurface only

Pw Weber Sandstone – subsurface only

Oquirrh Formation

Pogu **Granger Mountain Member, upper unit** -- Interbedded, medium- to thick-bedded, commonly bioturbated, fine-grained, commonly calcareous, feldspathic sandstone, and dark-gray, laminated to thin-bedded, pyritic siltstone; poorly exposed; sandstones form more rounded exposures than Pennsylvanian strata; only the lower 2,000 feet (610 m) crop out in the quadrangle, but the sequence is 10,250 feet (3,125 m) thick at Wallsburg Ridge, about 5 miles (8 km) west of the quadrangle.

Pogl **Granger Mountain Member, lower unit** -- Medium- to very thick-bedded, medium-gray, ledge-forming, fossiliferous limestone with few thin beds and nodules of black chert separated by middle, slope-forming, yellowish-brown, calcareous siltstone unit with few thin limestone interbeds; abundant benthonic fusilinids, locally common solitary and colonial corals, bryozoans, crinoid stems; 300 to 500 feet (91-152 m) thick.

IPowr **Wallsburg Ridge Member** -- Thick- to very thick-bedded, yellowish-brown, siliceous, feldspathic sandstone (orthoquartzite); common conchoidal fracture; locally laminated to cross-bedded; bedding commonly difficult to determine; includes few thin, silty and sandy limestone interbeds; about 3,700 feet (1,128 m) thick.

IPosm **Shingle Mill Limestone Member** -- Consists of two principal limestone intervals separated by a thick sequence of thin- to very thick-bedded, yellowish-brown to light-olive-gray, very fine- to medium-grained, commonly calacreous, slightly feldspathic sandstone with low-angle cross-bedding; limestone is thin to very thick bedded, gray, with black chert stringers and nodules; uncommon crinoid stems, solitary corals, and brachiopods; lower limestone commonly poorly exposed; about 380 to 510 feet (116-155 m) thick.

IPobc **Bear Canyon Member**-- Sandstone with lesser interbedded limestone; sandstone is yellowish brown, very fine grained, feldspathic, siliceous or calcareous, and commonly finely laminated; limestone is medium to thick bedded, medium gray with local black chert nodules and stringers, commonly has coarser grained, brown-weathering planar cross-laminae that stand in relief, and local crinoid stems, bryozoans, and brachiopods; only about the lower 2,000 feet (610 m) exposed, but the formation is about 4,600 feet (1,402 m) thick in the West Daniels Land #1 well.

IPobv Bridal Veil Falls Limestone Member – subsurface only

MISSISSIPPIAN

Mmc Manning Canyon Shale - subsurface only

CAMBRIAN

Ct? Tintic Quartzite? - subsurface only

Map Symbols

	Contact, dashed where approximately located
	Mass-movement scarp, hachures on down-dropped side
	Axis of double-crested ridge associated with possible sackungen
mb	Marker bed
m	Moraine crest
	Normal fault, dashed where approximately located, dotted where concealed, queried where uncertain; bar and ball on down-thrown side; no bar and ball indicates brecciated zone with unknown offset
	Thrust fault, dotted where concealed, queried where uncertain; teeth on upper plate
	Approximate axial trace of anticline, showing direction of plunge
	Approximate axial trace of syncline
30	Strike and dip of inclined bedding
15	Approximate strike and dip of inclined bedding determined from stereoplotter
	Approximate strike and dip direction of inclined bedding
	Spring
	Quarry, sandstone (no letter), quartzite (q)
	Pit, sand and gravel or borrow material
	Oil exploration test hole, plugged and abandoned
CC7899-1	Sample location and number
	Measured section location

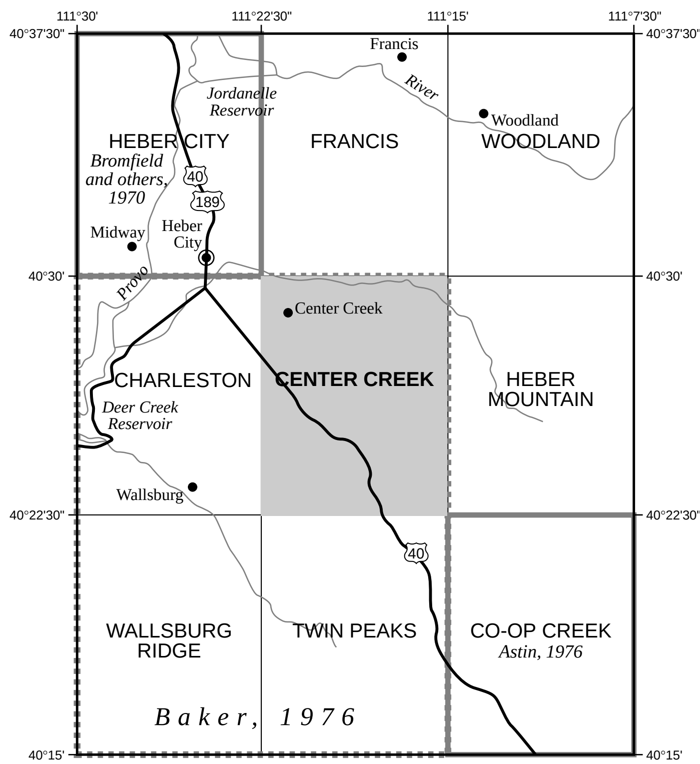


Figure 1. Index map showing the Center Creek 7.5-minute quadrangle and surroundingarea. Geologic maps of adjacent quadrangles are also shown; Byrant's (1992) 1:125,000-scale geologic map of the Salt Lake City 1°x 2° quadrangle covers all of these quadrangles.

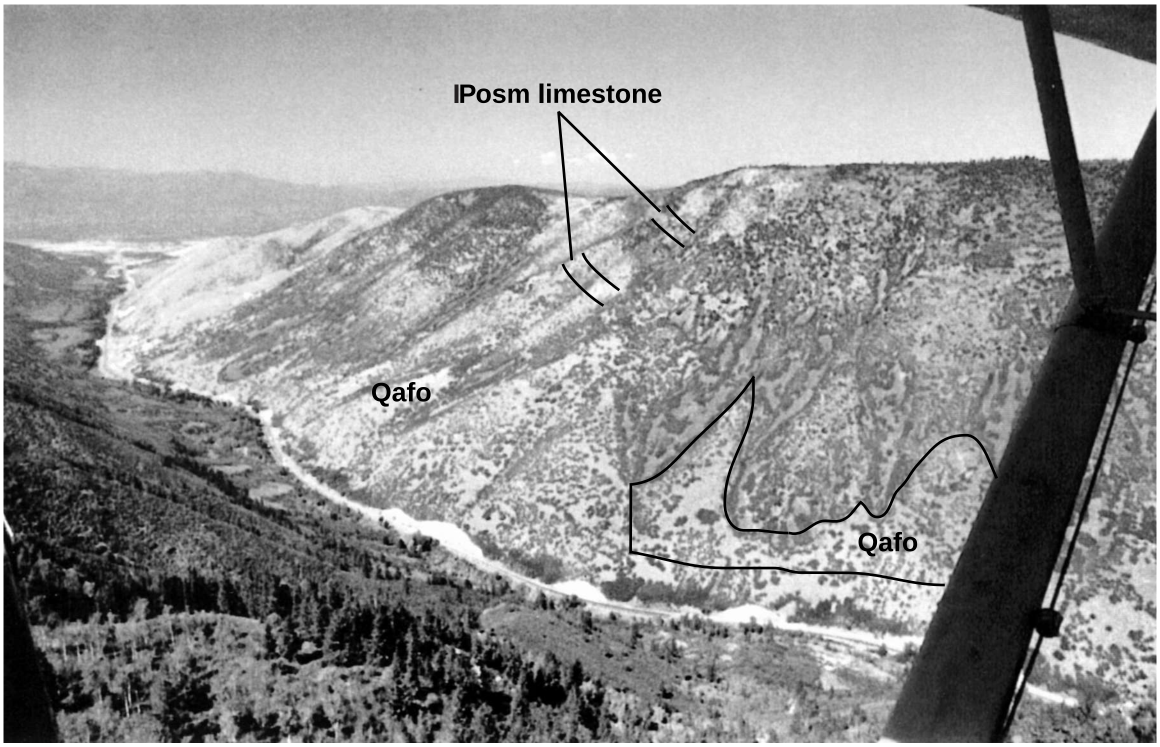


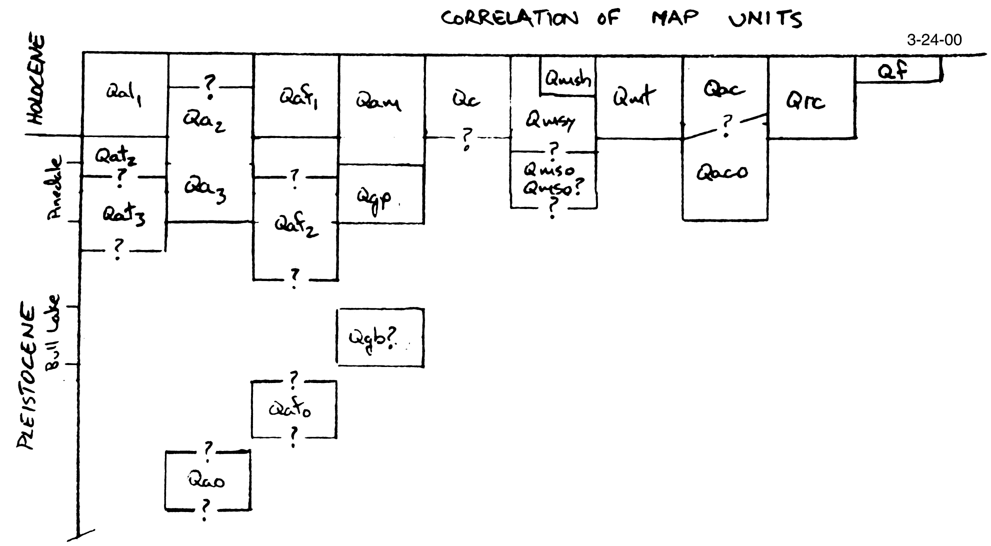
Figure 2. Oblique view of the south-facing slope of Hogsback Ridge in the lower reaches of Daniels Canyon. Note ledges of the Shingle Mill Limestone Member (IPosm) that are exposed on the southeast-plunging nose of the Daniels Canyon anticline. Older alluvial-fan deposits (Qafo) and talus, characterized by stone stripes, cover a mid-level bench and adjacent slopes carved into Oquirrh strata. Photograph taken in 1981.

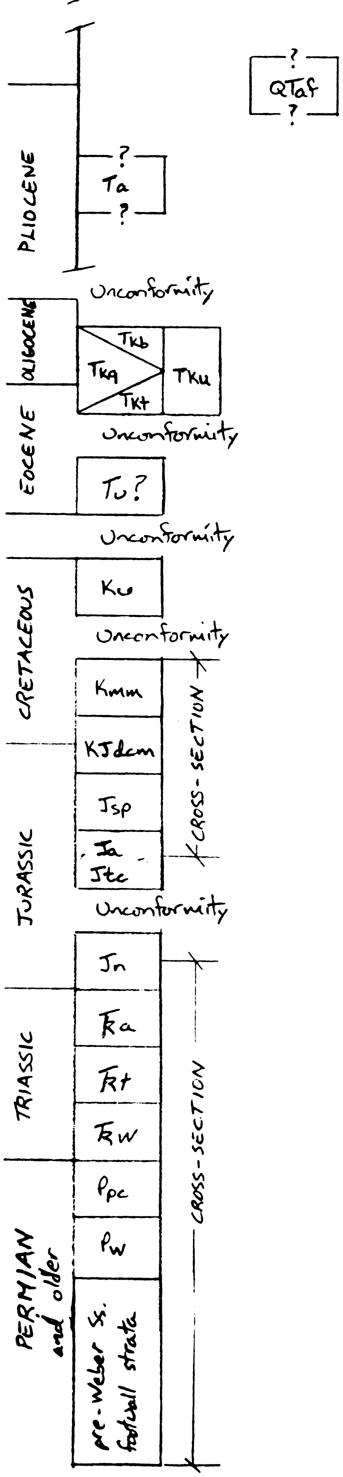
Figure 3. Volcanic breccia of Coyote Canyon exposed in cliff face at head of cirque, section 22, T. 4 S., R. 6 E. Hammer is at intraformational contact between two thick debris-flow beds that fine upward.

Figure 4. Oblique aerial view of the late Tertiary erosional surface preserved above Daniels Canyon. Row Hollow, in the adjacent Twin Peaks quadrangle, is at the lower left of the photograph. Photograph taken in 1981.

Figure 5. White, pedogenic carbonate horizon developedin till, exposed in south slope of ravine in SW1/4SE1/4 section 4, T. 4 S., R. 6. E.; note hammer for scale. The north slpoe of this ravine exposes a moderately well-developed Bt soil horizon. Soil development suggest till may be of Bull Lake age.

3-24-00





INTERIM GEOLOGIC MAP OF THE CENTER CREEK 7.5' QUADRANGLE, WASATCH COUNTY, UTAH

by

R.F. Biek, M.D. Hylland, J.E. Welsh, and Mike Lowe

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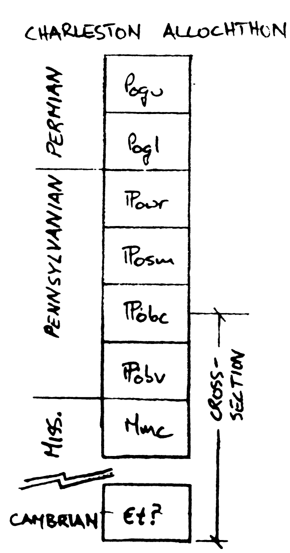

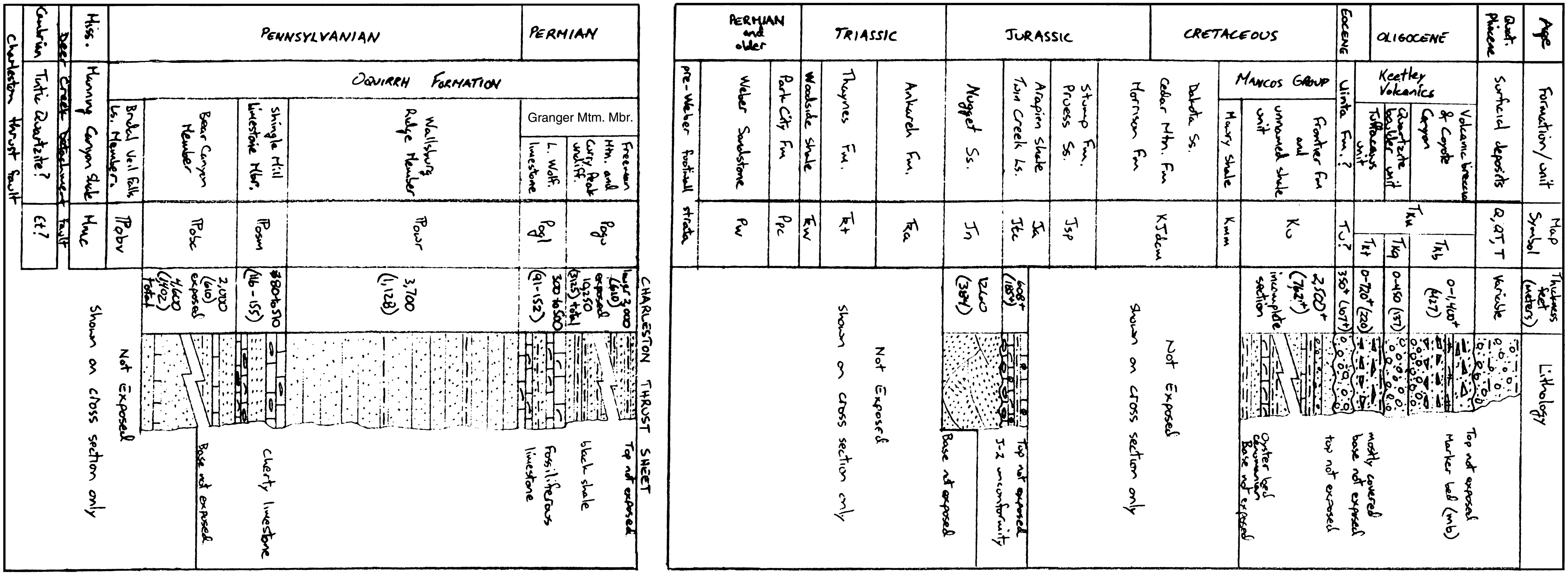

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U.S. Geological Survey

Interim Geologic Map of the Center Creek Quadrangle Wasatch County, Utah

by

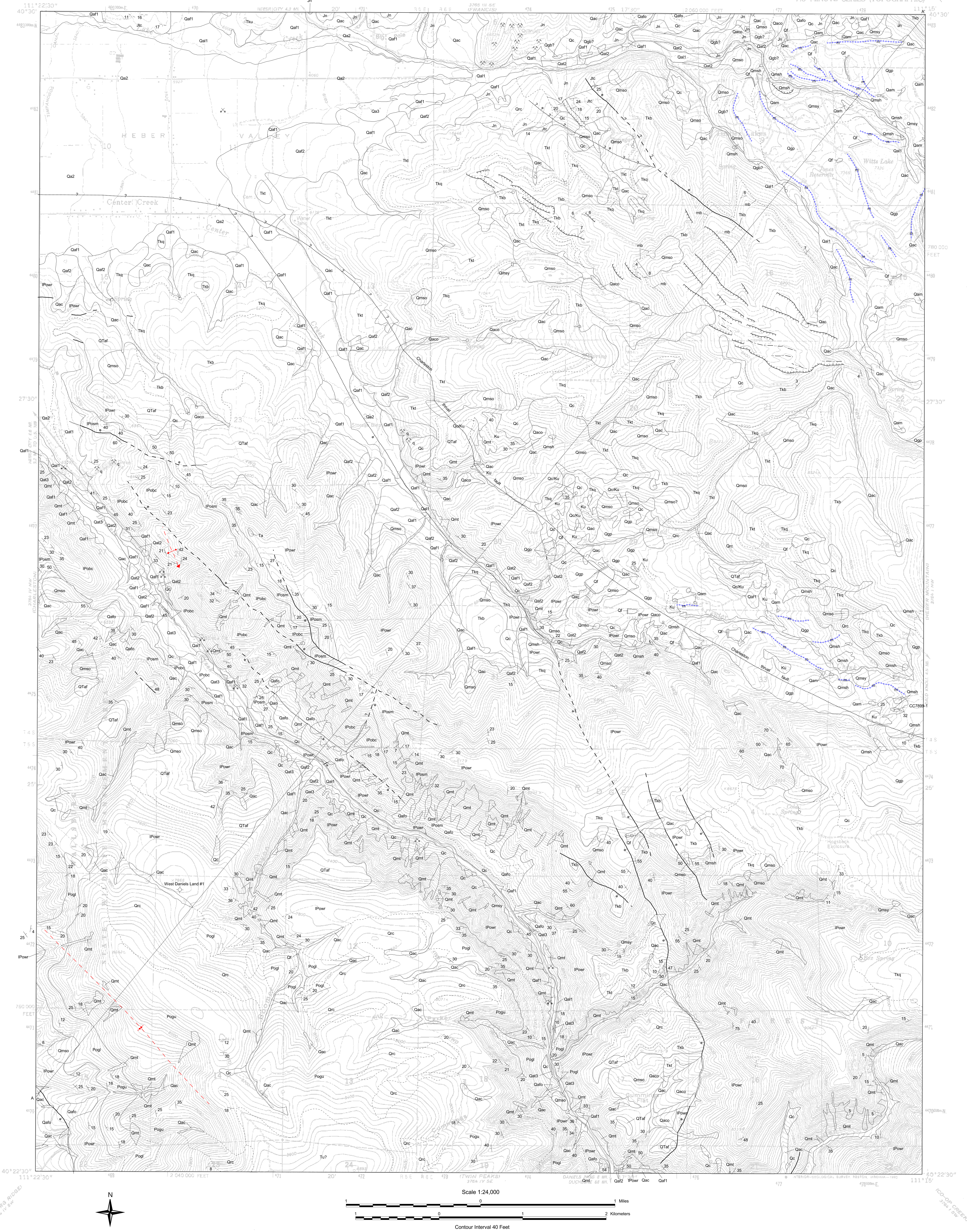
Robert F. Biek, Michael D. Hylland, Mike Lowe, and John E. Walsh

2000

Plate 1
Utah Geological Survey Open-File Report 370
Interim Geologic Map of the Center Creek Quadrangle

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

CENTER CREEK QUADRANGLE
UTAH–WASATCH CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Projection: UTM
Zone: 12
Datum: NAD 27
Spheroid: Clarke, 1866

NOT TO EXACT SCALE